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Patterns of habitat suitability and abundance trends of current and candidate coastal fish species of concern in Louisiana

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PATTERNS OF HABITAT SUITABILITY AND ABUNDANCE
TRENDS OF CURRENT AND CANDIDATE COASTAL FISH
SPECIES OF CONCERN IN LOUISIANA

A Thesis
Submitted to the Graduate Faculty of the
Louisiana State University and
Agricultural and Mechanical College
in partial fulfillment of the
requirements for the degree of
Master of Science

in

Department of Oceanography and Coastal Sciences

by
Elin Rose Sandy
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ABSTRACT

Louisiana's estuaries and coastal waters play an important role in providing habitat for several estuarine-dependent species and also serve as a nursery for the juveniles of several other species. The current rate of land loss in Louisiana and the decline of estuarine-dependent species force us to improve our understanding of the recruitment of these species into Louisiana's estuaries. Habitat suitabilities were developed for several fish species of concern (SOC) and other estuarine-dependent species across three environmental gradients, abundance patterns were developed for seasons, five-year intervals, and coastal study areas (CSAs). Chi-square analyses and ANOVAs were then used to test for differences in the suitability patterns and abundance patterns, respectively. The pipefish species, chain pipefish, *Syngnathus louisianae* (SOC) and gulf pipefish, *Syngnathus scovelli*, had significantly different suitability patterns for all three environmental variables. Chain pipefish suitability patterns were significantly different for all three variables, whereas, gulf pipefish only had strong patterns for salinity and Secchi depth. The pipefishes also had different temporal and spatial abundance patterns. The two goby species, violet goby, *Gobioides broussonnetii* (SOC) and sharptail goby, *Gobionellus hastatus*, had similar suitability patterns for all three environmental variables, but for sharptail goby did not have a strong salinity suitability pattern. They also had similar seasonal abundance patterns with peaks during the spring months. The three SOC fundulids, diamond killifish, *Adinia xenica*, bayou killifish, *Fundulus pulvereus*, and saltmarsh topminnow, *Fundulus jenkinsi*, shared similar, strong patterns of suitability for temperature and salinity. For Secchi depth, only diamond killifish and bayou killifish had strong suitability patterns. All three species also shared seasonal abundance patterns with peaks in the winter, and spatial abundance patterns with peaks in the central CSAs. The two candidate SOC, Atlantic threadfin, *Polydactylus octonemus* and

southern puffer, *Sphoeroides nephelus*, were chosen for further analyses based on their declining annual abundances. They did not have any similar temporal or spatial abundance patterns. The two species had strong suitability patterns for all three environmental variables; however, they did not share any similar patterns. The strong suitability patterns suggest that some of the environmental variables effect habitat selection for several of these species.

CHAPTER 1. GENERAL INTRODUCTION

Louisiana's estuarine and coastal waters play an important role by providing habitat for an abundant and diverse fauna of fishes and invertebrates (Beck et al. 2001, Boesch and Turner 1984). Louisiana's coastal systems act as nurseries for many estuarine-dependent fishes leading to higher concentration of individuals when compared to surrounding areas (Pearcy and Myers 1974). Saltmarsh estuaries can increase the growth and survival rates of many species that find environmental conditions within estuaries to be tolerable and more attractive than nearby areas (Boesch and Turner 1984). The recent rate of coastal land loss in coastal Louisiana is $33.67 \text{ km}^2\text{year}^{-1}$ (Barras et al. 2003). A decline the abundance and diversity of estuarine-dependent species (Houde and Rutherford 1993) and juveniles in the past few decades compels us to improve our understanding of species environmental requirements that affect recruitment by these species into estuaries and coastal waters.

Estuarine-dependence describes an organism's need for specific environmental conditions (Pearcy and Myers 1974, Weinstein 1979) generally found in reduced salinity waters. The declining numbers of some estuarine-dependent fishes in the past lead to their placement on Louisiana's species of concern list. The study of habitat selection of these estuarine-dependent fish species of concern offers insights into factors that may have led to their decline by providing information on their distribution patterns across environmental gradients that reflect population responses to optimal and undesirable conditions. There are many factors, both physiochemical (e.g., salinity, temperature, and turbidity) and biotic (e.g., predation and competition) that may play a role in the distribution and abundance patterns of estuarine fishes (Rozas and Zimmerman 2000). The patterns of abundance of individuals along environmental gradients should also provide information on the tolerance limits of species (Jobling 1981, 1994, Magnuson et al.

1979). Many species, however, may not occupy preferred microhabitats because of the presence of predators or competitors (Baltz et al. 1982, Fraser and Sise 1980, Hixon, 1980, Werner et al. 1977). Studying the distribution and abundance of fishes on a fine spatial scale has been used to determine habitat selection. We may define a microhabitat as a site that an individual or group of fishes occupies at a given point in time (Baltz 1990). Measurements of the environmental conditions at these occupied sites provide information on a species' patterns of abundance and distribution because similar-sized individuals of a species utilize sites with similar conditions (Hurlbert 1981, Baltz et al. 1987, Baltz 1990).

Fishes are unusual as they continue to grow throughout their lives and their habitat requirements often change with size and age (Livingston 1988). Table 1.1 lists the size at maturation for all species in this study.

Table 1.1 Size at maturity (mm SL) with citations for all species in this study.

Common name	Scientific name	Size at maturity (mm SL)	Citations
chain pipefish	<i>Syngnathus louisianae</i>	101	Dawson 1972
gulf pipefish	<i>Syngnathus scovelli</i>	55	Joseph 1957
violet goby	<i>Gobioides broussonnetii</i>	100	Dawson 1969
sharptail goby	<i>Gobionellus hastatus</i>	60	Dawson 1969
diamond killifish	<i>Adinia xenica</i>	19	Hastings and Yerger 1971
bayou killifish	<i>Fundulus pulvereus</i>	29	Boschung and Mayden 2004, Cook 1959
saltmarsh topminnow	<i>Fundulus jenkinsi</i>	21	Thompson 1999
Atlantic threadfin	<i>Polydactylus octonemus</i>	100	Dentzau and Chittenden 1990
southern puffer	<i>Sphoeroides nephelus</i>	165	Shipp and Yerger 1969

Three chapters in this thesis compare habitat suitability and abundance patterns among nine species. Chapter three evaluates two fish species of concern (SOC) to two similar species that are not at risk of extinction or declining. The SOC violet goby (*Gobioides broussonnetii*) is compared to sharptail goby (*Gobionellus hastatus*), and the SOC chain pipefish (*Syngnathus louisianae*) is compared to gulf pipefish (*Syngnathus scovelli*). The sharptail goby and the gulf

pipefish were chosen as comparisons based on their similarities in size to the SOC's and their higher abundances compared to the SOC's. The ranking system for Louisiana for species of concern (LDWF 2005) are ordered in five categories: S1 is critically imperiled because of extreme rarity, S2 is imperiled because of rarity, S3 is rare or found locally, S4 is apparently secure with many occurrences, and S5 is demonstrably secure. Both of the violet goby and the chain pipefish are listed as apparently secure (S4) in Louisiana. Chapter four evaluates three SOC in the family Fundulidae, diamond killifish (*Adinia xenica*), bayou killifish (*Fundulus pulvereus*), and saltmarsh topminnow (*Fundulus jenkinsi*). Saltmarsh topminnow is listed as an imperiled and vulnerable SOC (S2) with a moderate to high risk of extinction due to highly restricted habitat range, few populations, and steep declines in populations. Both diamond killifish and bayou killifish are listed as apparently secure (S4) in Louisiana with several occurrences recorded. Chapter five evaluates two species, Atlantic threadfin (*Polydactylus octonemus*) and southern puffer (*Sphoeroides nephelus*) which have shown an abrupt decline in abundance since 1991 indicating a change in status as candidates for SOC listing.

By comparing the patterns of environmental use for these species with the patterns of resource availability, I tested whether: (1) these species shared similar patterns of resource utilization within the Louisiana estuaries, and (2) their resource utilization was similar to the environmental availability. I also compared patterns of relative abundance by evaluating the catch per unit effort (CPUE) by seasons, five-year intervals, and across seven coastal study areas (CSA) that span the Louisiana coast. I tested whether their relative abundances within species were: (1) similar for all four seasons, (2) similar for each of the five-year intervals, and (3) similar for each of the CSAs. Finally, I tested to determine whether there was any correlation between four climatic variables, Oceanic Niño Index (ONI), precipitation, Mississippi and

Atchafalaya river discharges and gulf water surface elevation (WSE), and annual abundances for each species.

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CHAPTER 2. MATERIALS AND METHODS

STUDY AREA

The study area in Louisiana's estuarine and coastal environments consists of fresh, brackish, and saltwater marshes and adjacent waters. Seasonal mean water temperatures from Louisiana Department of Wildlife and Fisheries (LDWF) databases for winter through fall are 13.8, 22.0, 29.6, and 23.9 °C, respectively. The estuaries are microtidal with a mean amplitude of 0.3 m, the tides are primarily diurnal, and the waters are relatively shallow, and moderately to highly turbid (Baltz and Jones 2003). Winds are the primary factor driving water circulation, sediment suspension and sediment transport (Walker and Hammack 2000).

Coastal Louisiana has been stratified (Table 2.1 and Fig. 2.1) into seven coastal study areas (CSA) (LDWF 2002). Table 2.1 gives the eastern and western boundaries for each CSA, as well as, the major water bodies within each CSA. One major water body has been chosen to identify each CSA throughout the remainder of the thesis and has been depicted in the table with bold lettering.

Table 2.1 Stratification of coastal study areas (CSAs) including eastern and western boundaries, strata names (bold), and major water bodies.

Coastal study area	Eastern boundary	Western boundary	Strata names: Major water bodies
1	Mississippi state line	Bayou Terre aux Boeufs	Chandeleur Stratum: Chandeleur Sound, Mississippi Sound, Lake Bourgne, Lake Ponchartrain, Lake Maurepas
2	Bayou Terre aux Boeufs	Grand Bayou	Mississippi River Stratum: Breton Sound, Black Bay, Bay Gardene, Bay Crabe, American Bay, California Bay, Quarantine Bay, Grand Bay, Mississippi River, Little Lake, Bay Adams, Bay Jacques, Skipjack Bay, Sandy Point Bay, Bay Lanaux
3	Grand Bayou	Bayou Lafourche	Barataria Stratum: Barataria Bay, Caminada Bay, Little Lake
4	Bayou Lafourche	Bayou Sale	Terrebonne/Timbalier Stratum: Terrebonne and Timbalier bays, Lake Pelto
5	Bayou Sale	Atchafalaya River/Point au Fer Island	Caillou Stratum: Caillou Bay, Caillou Lake, Lake Mechant, Lake Decade, Four League Bay
6	Atchafalaya River	Freshwater Bayou	Atchafalaya Stratum: Vermillion Bay, West Cote Blanche Bay, East Cote Blanche Bay, Atchafalaya Bay
7	Freshwater Bayou	Texas state line	Rockefeller Refuge Stratum: Rockefeller Wildlife Refuge complex, Mermentau River Basin, Calcasieu Lake, Lake Charles, Prien Lake, Sabine Lake

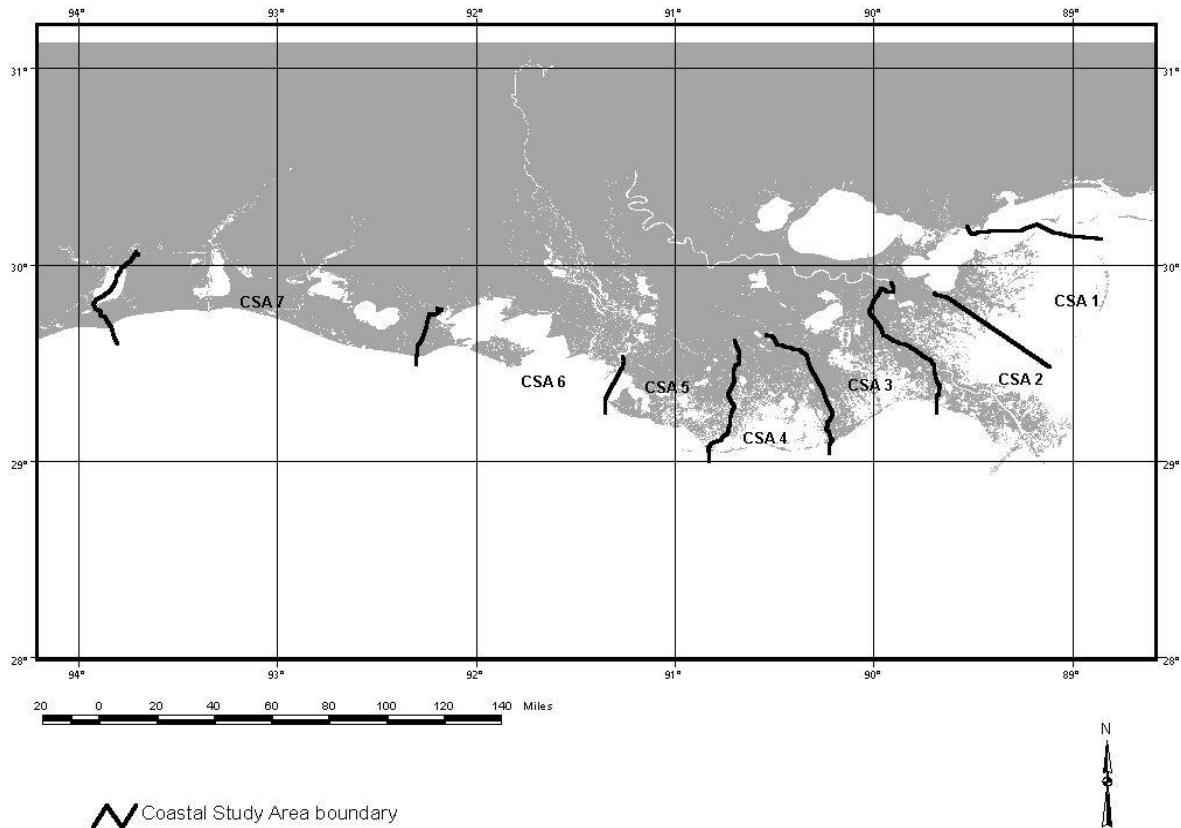


Figure 2.1 The Louisiana coast divided into seven Coastal Study Areas (LDWF 2002).

DATA COLLECTION

Data from fishery-independent sampling and associated environmental variables were collected and processed by LDWF for two programs monitoring shrimp and fish populations (LDWF 2002). From the monitoring programs, data from two gear types, which accounted for the majority of the data, were chosen for analysis: 4.9 m (16 ft) flat otter trawl and 15.2 m (50 ft) bag seine. These gears have been used by LDWF to monitor relative abundances, size distributions, and seasonal and long-term trends of various marine organisms since 1966 for trawls and since 1986 for seines, and both programs have continued through the present.

Otter trawl sampling is used primarily to assess penaeid shrimp, but also blue crabs (*Callinectes sapidus*), finfish (bottomfish), and other marine organisms in the larger bays and

nearshore coastal waters. The 4.9 trawl consists of two main sections: the body, which is constructed with 1.9 cm ($\frac{3}{4}$ inch) bar mesh of No. 9 twine, and the tail, which is constructed with 0.635 cm ($\frac{1}{4}$ inch) bar mesh and is 1.37 to 1.524 m (54 to 60 inches) long. Sampling frequency for the trawls differed depending on whether the sampling site was in bays or in the Gulf of Mexico. Inshore sampling occurred every other week from November through February and weekly for March through October. Gulf sampling occurred every other week from November through March, and weekly from March through October. Trawls were towed for ten minutes at a constant speed and in a circular motion, allowing the propeller wash to pass on the side of the trawl. Organisms in the trawl were separated by species, counted, and up to fifty individuals of each species were randomly selected and measured in 5 mm intervals. Size measurements were taken for shrimp from the anterior tip of the rostrum to the posterior tip of the telson (TL), for crabs as carapace width (CW), and for fish as total length (TL) (LDWF 2002).

The juvenile fish monitoring program used 15.2 m seines to assess fishes, shellfish, and other marine organisms. The seine was constructed of 0.635 cm ($\frac{1}{4}$ inch) bar mesh, 1.83 m (6 feet) deep, and had a 1.83 m x 1.83 m (6 ft x 6 ft) bag in the middle of the net. Sampling frequency for the seine was monthly from January through August and twice a month from September through December. Two standard sampling procedures were used based on bottom type (LDWF 2002). All organisms were identified and counted. For selected species only (LDWF 2002, Appendix 4) up to 30 individuals were measured in the same manner as for trawl samples.

Four climatic variables, Oceanic Niño Index (ONI), Mississippi River and Atchafalaya River discharges, precipitation, and gulf water surface elevation (WSE), were analyzed to determine any correlation with annual abundances for each fish species. The ONI records were

obtained from National Oceanic and Atmospheric Administration's (NOAA) National Climatic Data Center and are 3-month running means of the Extended Reconstruction Sea Surface Temperature (ERSST) anomaly (version 3b) (http://www.cpc.ncep.noaa.gov/products/analysis_monitoring/ensostuff/ensoyears.shtml, accessed 15 November, 2010). The ERSST analysis was based on the International Comprehensive Ocean-Atmosphere Data Set and was computed with respect to the 1971-2000 base period (Xue et al. 2003). The Mississippi River and the Atchafalaya River discharge records were obtained from the U.S. Army Corps of Engineers (USACE) Mississippi River gauging station near Tarbert Landing, Mississippi (<http://www.mvn.usace.army.mil/cgi-bin/wcmanual.pl?01100>, accessed 15 November 2010) and Atchafalaya River gauging station near Simmesport, Louisiana (<http://www.mvn.usace.army.mil/cgi-bin/watercontrol.pl?03045>, accessed 15 November 2010). Precipitation records were obtained from the NOAA National Climate Data Center (http://www7.ncdc.noaa.gov/IPS/cd/cd.html?_page=0&jsessionid=A50481FDDB5BC9A82BAC9B6604E51C59&state=LA&_target1=Next, accessed 15 November 2010). Gulf WSE records were obtained from the USACE Calcasieu River and Pass gauging station near Cameron, Louisiana (<http://www.mvn.usace.army.mil/cgi-bin/watercontrol.pl?73650>, accessed 15 November 2010).

DATA ANALYSIS

To evaluate changing environmental conditions three environmental variables ($\log x+1$), temperature, salinity, and Secchi depth, were analyzed to describe patterns or correlations. General Linear Models (GLM) procedure and the least-square-mean (LSM) comparisons with Tukey's adjustment (SAS Institute 2002) were used in one-way analyses of variance (ANOVAs) to test means among seasons, five-year intervals, and across coastal study areas. Four seasons were defined as spring (March through May), summer (June through August), fall (September

through November), and winter (December through February). Pearson's correlation coefficients were used to evaluate relationships among environmental variables (PROC CORR, SAS Institute 2002). Similar tests of relative abundances compared catch per unit effort (CPUE) means within a species on seasonal, five-year interval and spatial scales.

Environmental and catch data were analyzed to describe patterns of resource availability, habitat use, habitat selection, and temporal and spatial trends. The habitat suitability index (Bovee 1982) was used to identify trends in selection and avoidance along three environmental gradients. Suitability patterns were derived by first obtaining information about the patterns of resource availability for each variable: temperature, salinity, and water clarity as estimated by Secchi depth. To characterize resource availability, frequency distribution patterns of unweighted data (data taken per sample) for each variable of interest for the entire study area and time period regardless of the presence of species was summarized. Resource use patterns were established by developing frequency distributions of species habitat use weighted by the number of individuals present per sample. Raw suitability (S_{raw}) (Bovee 1982) was defined as:

$$S_{raw} = \frac{P(E|F)}{P(E)} = \frac{\text{proportional use}}{\text{proportional availability}},$$

where $P(E | F)$ is the probability (from frequency use data for a species) finding a value of a given variable (E) given the presence of fish (F), and $P(E)$ is the probability (from frequency availability data) of finding a value of a given variable regardless of whether fish are present or not. Raw suitability patterns were then normalized, and thereafter referred to as suitability curves, with values ranging from a minimum of 0 for undesirable conditions to a maximum of 1 for near optimal conditions. Suitability curves were graphed with use and availability distributions (Baltz 1990). Three-point moving averages were used to smooth the suitability curves.

For statistical analyses, the temperature, salinity, and Secchi depth were categorized in bins of 2 °C, 2, and 10 cm, respectively. Chi-square tests of independence (Jelinski 1991) were examined to evaluate the distribution patterns of resource availability and use for each species and to compare patterns of resource use between species (PROC FREQ, SAS Institute 2002). Separate tests were conducted for each environmental variable.

Changes in species abundance across seasons, longer time intervals and spatially, were evaluated by examining temporal patterns in relative abundance (CPUE) of species. The seasonal analysis used data for four seasons (winter: Dec-Feb, spring: Mar-May, summer: Jun-Aug, and fall: Sept-Nov) to determine trends in relative abundance for each species. For longer-term temporal analysis, relative abundances for five-year intervals (i.e., semi-decadal), except for the last interval which only included two years (2006 and 2007) were evaluated. Pseudoreplication (Hurlbert 1984) was avoided by using the PROC SUMMARY with a frequency weight statement (SAS Institute 2002) to reflect population responses across gradients without increasing degrees of freedom.

Annual means were calculated for each of the climatic variables and the data were then mean-centered for graphing. For the ONI, annual means were calculated from the 12 3-month running mean of the ERSST anomaly for each year. For the Mississippi River and Atchafalaya River discharges, annual means were calculated from summed daily records from both stations. Annual means for precipitation were calculated from three annual records for the southern divisions in Louisiana (Southwest, South central, and Southeast). For gulf WSE, annual means were calculated from daily records. Pearson's correlation coefficients were used to evaluate relationships between climatic variables and annual abundances for each fish species (PROC CORR, SAS Institute 2002). The Dunn-Šidák correction for multiple comparisons (Sokal and

Rohlf 1995) was applied to the criterion α level of 0.05 to reduce the probability of a Type I error.

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CHAPTER 3. COMPARING HABITAT SUITABILITY AND ABUNDANCE OF TWO FISH SPECIES OF CONCERN TO CLOSELY RELATED SPECIES

RESULTS

Environmental Variation

Two gear types were used in the data collection and resulted in slightly different pictures of environmental variation because of different sampling frequencies. Data were collected for with 15.2 m bag seines and 2.9 m otter trawls. Frequency distribution patterns for resource availability were tabulated (Table 3.1) for three environmental variables for both gear types.

For the seines, the mean (\pm SE) temperature for the entire study period was 22.4 ± 0.06 °C and ranged from a minimum of 8.0 to a maximum of 32.0 °C. About 70% of temperatures recorded for the entire study period were between 18 and 30 °C (Fig. 3.2). Mean (\pm SE) salinity for the entire study period was 10.5 ± 0.07 and ranged from a minimum of 0.0 to a maximum of 32.0. About 85% of salinities recorded were between 0 and 18 (Fig. 3.3). Mean (\pm SE) Secchi depth for the entire study period was 58.7 ± 0.34 cm and ranged from a minimum of 10 to a maximum of 120 cm. About 62 % of Secchi depths were between 20 and 60 cm (Fig. 3.4). All of the overall tests using one-way ANOVAs were highly significant ($F \geq 14.4$, $df \geq 3$, 11181, $p \leq 0.0001$). Secchi depth was negatively correlated with temperature ($r = -0.10$, $p \leq 0.0001$) and positively correlated with salinity ($r = 0.25$, $P < 0.0001$). Correlations between temperature and salinity were not significant ($p = 0.10$).

Mean seine temperatures were significantly different (one-way ANOVAs, $F \geq 14.4$, $df \geq 3$, 11186, $p \leq 0.0001$) across all seasons, several five-year intervals, and several CSAs (Table 3.1). The highest temperatures were during summer and lowest were during winter. Temperatures were highest during the 1986-1990 interval and lowest during the 1991-2007

interval. Mississippi River, Barataria, Terrebonne/Timbalier, and Caillou strata had the highest temperatures and Rockefeller Refuge stratum had the lowest.

Table 3.1 Seining (1986 – 2007) and trawling (1966 – 2007) means (± 1 SE) for the three variables by seasons, five-year intervals, coastal study areas. Reading vertically, the letters indicate statistical differences of the three environmental variables across the seasons, years, and CSAs. The two gear types were analyzed separately.

Temperature			Salinity		Secchi Depth	
Seasons	Seine	Trawl	Seine	Trawl	Seine	Trawl
Spring	22.6 \pm 0.09 a	22.0 \pm 0.04 a	8.7 \pm 0.15 a	11.3 \pm 0.07 a	52.3 \pm 0.61 a	52.7 \pm 0.34 a
Summer	39.8 \pm 0.03 b	29.6 \pm 0.01 b	9.5 \pm 0.15 b	12.8 \pm 0.07 b	53.7 \pm 0.54 b	62.2 \pm 0.41 b
Fall	23.5 \pm 0.08 c	23.9 \pm 0.05 c	12.6 \pm 0.12 c	16.0 \pm 0.08 c	62.6 \pm 0.64 c	67.6 \pm 0.51 c
Winter	14.6 \pm 0.07 d	13.8 \pm 0.04 d	9.9 \pm 0.14 d	14.2 \pm 0.11 d	63.1 \pm 0.78 d	63.5 \pm 0.59 d
Years						
1966-1970	n/a	24.2 \pm 0.38 a	n/a	14.0 \pm 0.38 ad	n/a	31.0 \pm 1.70 a
1971-1975	n/a	22.8 \pm 0.10 bc	n/a	10.8 \pm 0.14 b	n/a	43.8 \pm 0.72 b
1976-1980	n/a	22.8 \pm 0.13 c	n/a	13.5 \pm 0.15 c	n/a	50.5 \pm 0.93 c
1981-1985	n/a	23.7 \pm 0.10 ad	n/a	15.2 \pm 0.13 ad	n/a	55.0 \pm 0.59 d
1986-1990	23.4 \pm 0.13 a	23.8 \pm 0.08 ad	12.2 \pm 0.15 a	16.1 \pm 0.11 a	56.6 \pm 0.72 a	65.1 \pm 0.64 ef
1991-1995	22.5 \pm 0.15 b	23.6 \pm 0.08 ad	8.6 \pm 0.17 b	11.8 \pm 0.10 e	62.2 \pm 0.87 a	62.9 \pm 0.53 ef
1996-2000	22.0 \pm 0.12 b	23.3 \pm 0.08 bd	10.7 \pm 0.14 c	14.6 \pm 0.10 cd	64.4 \pm 0.74 b	67.3 \pm 0.50 e
2001-2005	22.1 \pm 0.11 b	23.1 \pm 0.06 bcd	9.4 \pm 0.13 d	11.7 \pm 0.07 e	56.0 \pm 0.62 a	64.5 \pm 0.55 f
2006-2007	22.3 \pm 0.22 b	22.5 \pm 0.11 bd	12.8 \pm 0.25 a	13.7 \pm 0.14 c	50.1 \pm 0.72 c	63.5 \pm 0.80 f
Coastal Study Area						
Chandeleur stratum	22.2 \pm 0.17 a	23.4 \pm 0.09 a	11.9 \pm 0.17 a	9.4 \pm 0.08 a	91.4 \pm 1.07 a	92.0 \pm 0.68 a
Mississippi River stratum	22.5 \pm 0.15 abc	23.4 \pm 0.43 ab	7.4 \pm 0.13 b	13.4 \pm 0.09 b	74.8 \pm 1.22 b	63.4 \pm 0.57 b
Barataria stratum	23.2 \pm 0.20 bc	23.8 \pm 0.06 c	10.2 \pm 0.25 c	16.4 \pm 0.10 b	53.1 \pm 0.63 c	68.2 \pm 0.53 c
Terrebonne/Timbalier stratum	22.6 \pm 0.14 abc	23.6 \pm 0.08 bc	13.4 \pm 0.20 d	19.8 \pm 0.10 c	56.0 \pm 0.68 d	67.7 \pm 0.75 b
Calliou stratum	23.2 \pm 0.15 b	24.0 \pm 0.08 c	12.3 \pm 0.20 a	13.6 \pm 0.11 d	60.3 \pm 0.70 e	55.3 \pm 0.47 d
Atchafalaya stratum	22.4 \pm 0.16 ac	22.8 \pm 0.08 d	5.1 \pm 0.11 e	7.7 \pm 0.08 e	28.0 \pm 0.52 f	33.0 \pm 0.23 e
Rockefeller Refuge stratum	21.1 \pm 0.17 d	22.7 \pm 0.08 d	13.8 \pm 0.17 d	13.7 \pm 0.09 f	48.8 \pm 0.68 g	59.9 \pm 0.67 f
Overall	22.4 \pm 0.06	23.4 \pm 0.03	10.5 \pm 0.07	13.4 \pm 0.04	58.7 \pm 0.34	60.8 \pm 0.22

Mean seine salinities were significantly different (one-way ANOVAs, $F \geq 131.9$, $df \geq 3$, 11181, $p \leq 0.0001$) across all seasons, several five-year intervals, and several CSAs (Table 3.1).

The highest salinities were during fall and lowest were during spring. For five-year intervals,

salinities were highest during the 1986-1990 and 2006-2007 intervals. The lowest salinities were during the 1991-1995 interval. Terrebonne/Timbalier and Rockefeller Refuge strata had the highest salinities and Atchafalaya stratum had the lowest.

Mean seine Secchi depths were significantly different (one-way ANOVAs, $F \geq 37.6$, $df \geq 3$, 14942, $p \leq 0.0001$) across all seasons, several five-year intervals, and several CSAs (Table 3.1). The highest depths were during winter and were lowest during spring. Depths were highest during the 1996-2000 interval and lowest during the 2006-2007 interval. For CSAs, the highest depths were in Chandeleur stratum and the lowest depths were in Atchafalaya stratum.

For the trawls, means (\pm SE) for temperature, salinity, and Secchi depth for the overall study period were 23.4 ± 0.03 °C, 13.4 ± 0.04 , and 60.8 ± 0.22 cm, respectively. Roughly 75% of temperatures recorded for the entire study period were between 20 and 30°C (Fig. 3.2), about 76% of salinities recorded were between 3 and 21 (Fig. 3.3), and 84% of Secchi depths were in the range of 20 and 90 cm (Fig. 3.4). The overall tests using one-way ANOVAs were highly significant ($F \geq 17.50$, $df \geq 3$, 42411, $p \leq 0.0001$). Secchi depth was positively correlated with temperature ($r = 0.10$, $p \leq 0.0001$) and negatively correlated with salinity ($r = -0.11$, $p \leq 0.0001$). Correlations between temperature and salinity were not significant ($p = 0.80$).

Patterns were similar to seine sampling (Table 3.1) with some exceptions. For trawl temperature, there were exceptions for both the five-year intervals and CSAs which were both significantly different (one-way ANOVAS, $F \geq 17.7$, $df \geq 6$, 42409, $p \leq 0.0001$). Temperatures were highest during the 1966-1970 and 1981-1995 intervals and lowest during the 1971-1980 intervals. Barataria, Terrebonne/Timbalier, and Caillou strata had the highest temperatures and Atchafalaya and Rockefeller Refuge strata had the lowest.

For trawl salinity, patterns of environmental variation were only similar to the seine dataset for seasons. One-way ANOVAs found the both five-year intervals and CSAs had significant differences ($F \geq 274.8$, $df \geq 6$, 42689 , $p \leq 0.0001$). Salinities were highest during the 1966-1970, 1981-1990, and 1996-2000 intervals and lowest during the 1971-1975 interval. For CSAs, salinities were highest in Terrebonne/Timbalier stratum and lowest in Atchafalaya stratum.

For trawl Secchi depth, there were exceptions for seasons and five-year intervals. One-way ANOVAs found both had significant differences ($F \geq 333.5$, $df \geq 3$, 42694 , $p \leq 0.0001$). For seasons, depths were highest in fall and lowest in spring. Secchi depths were highest during the 1986-2000 intervals and lowest during the 1966-1970 interval.

Annual means calculated for the Oceanic Nino Index (ONI), Mississippi and Atchafalaya River discharges, precipitation, and water surface elevation (WSE) were plotted (Fig. 3.1) and correlations were tabulated (Table 3.2) to determine any correlations with annual abundances for each species. For the ONI, Extended Reconstruction Sea Surface Temperature (ERSST) anomalies ≤ -0.5 °C indicate a La Niña event and anomalies ≥ 0.5 °C indicate an El Niño event. The strongest El Niño events (anomalies ≥ 1.0) were during 1987 (1.29) and 1997 (1.26), and the strongest La Niña events (anomalies ≤ -1.0) were during 1975 (-1.14) and 1999 (-1.06). River discharges were higher in 1973, 1979 and 1992 and lower in 1966, 1980, 1987 and 1999. Precipitation was higher in 1991-1992 and lower in 1999-2000. Gulf WSEs were higher in 1975, 1979 and 2005 and lower in 1966 and 1968-1970. There were no WSE data available for 2006 or 2007. The means (± 1 SE) for the entire study period (1966-2007) for the ONI, river discharges, precipitation, and WSE were 0.05 ± 0.04 °C, 0.96 ± 0.00 m³/s, 160.05 ± 3.48 cm, and

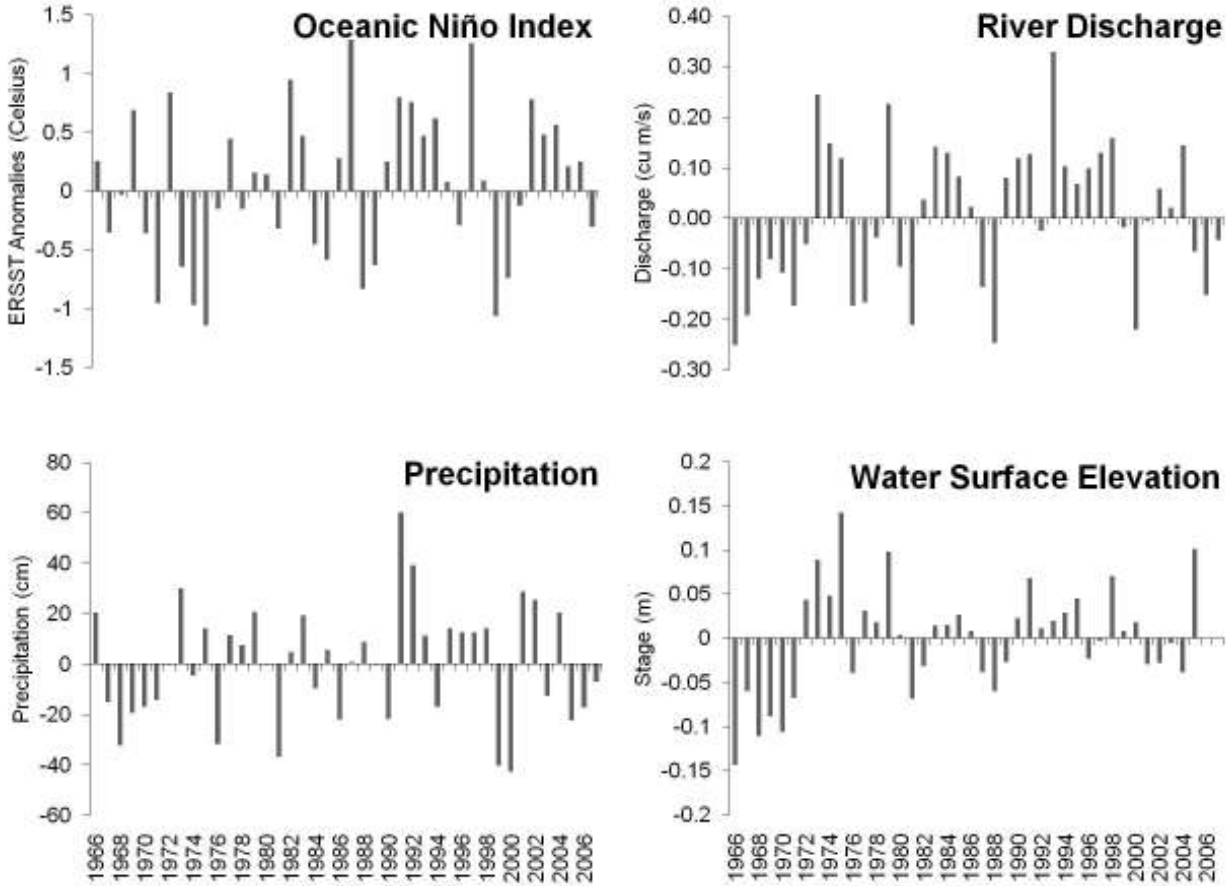


Figure 3.1 Mean-centered annual means (1966-2007) for the Oceanic Niño Index (ONI), Mississippi and Atchafalaya River discharges, coastal precipitation, and gulf water surface elevation.

Table 3.2 Pearson's correlation coefficients between the climatic variables and four species. Bold coefficients indicate significantly correlated values ($p \leq 0.002$).

	River discharges	Surface water elevation	Oceanic Niño Index	Violet goby	Sharptail goby	Chain pipefish	Gulf pipefish
Precipitation	0.33	0.22	0.32	-0.25	0.13	0.05	0.12
River discharges		0.33	0.04	-0.15	0.23	0.29	0.07
Surface water elevation			-0.01	-0.69	0.36	0.20	0.02
Oceanic Niño Index				0.12	0.28	0.09	0.13
Violet goby					0.01	0.00	-0.01
Sharptail goby						0.06	0.14
Chain pipefish							0.17

0.59 ± 0.00 m, respectively. There were no significant Pearson's correlations (Table 3.2) between any of the climatic variables.

Historical Trends

Annual catch per unit effort (CPUE) data were evaluated for each species to determine long-term trends in relative abundance (Fig. 3.2). For the pipefishes, the data were from the seine dataset and covered the period from 1986-2007. The abundances for chain pipefish were relatively similar across years with the highest CPUEs in 1994, 1998 and 2004 and the lowest in 1987, 1992 and 2006. Gulf pipefish had their highest abundances in 2002 and their lowest in 1986-1987, 1996 and 2006. For the gobies, the data came from the trawl dataset covering 1966-2007. Overall abundances for violet goby were lower than sharptail goby abundances. Violet goby had higher abundances in 1968-1969, 1971, 1998-1999, and 2004-2005. There were no violet gobies caught in the trawl for 1966, 1970-1971, and 1976-1979. For the sharptail goby, abundances were higher in 1992 and lower in 1966 and 1977 when no individuals were caught. Most linear regressions of CPUE on year were significant for chain pipefish, gulf pipefish and sharptail goby (chain pipefish: $y = 1997.65 + 0.11x$, $r = 0.02$, slope $p = 0.04$; gulf pipefish: $y = 1997.65 + 0.10x$, $r = 0.02$, slope $p \leq 0.0001$; sharptail goby: $y = 1991.08 + 0.19x$, $r = 0.01$, $p = 0.02$; violet goby $p > 0.05$). Pearson's correlations (Table 3.2) only showed one significant negative correlation between the annual abundance of violet goby and surface water elevation ($r = -0.69$, $p \leq 0.0001$).

Abundance Patterns

Most of the temporal and spatial abundance patterns, estimated with CPUE, of the pipefishes and gobies across seasons, five-year intervals, and CSAs (one-way ANOVAs: $F \geq 2.50$, $df \geq 3$, 15113 , $p \leq 0.06$) were highly significant with one exception for chain pipefish

seasonal abundances (Tables 3.3-3.5). The seine CPUEs for the entire study period for the chain pipefish and gulf pipefish were 0.16 and 0.19, respectively. The trawl CPUEs for the entire study period for the violet goby and sharptail goby were 0.00 and 0.05, respectively. The overall test for seasonal abundances for chain pipefish were not significantly different ($F = 2.50$, $df = 3$, 15116 , $p = 0.06$). For the gulf pipefish, the seasons were significantly different with highest abundances in spring and summer and lowest in fall. Violet goby reached the highest abundances during spring and other seasons were similar. Sharptail goby abundances were highest during spring and lowest during summer and fall.

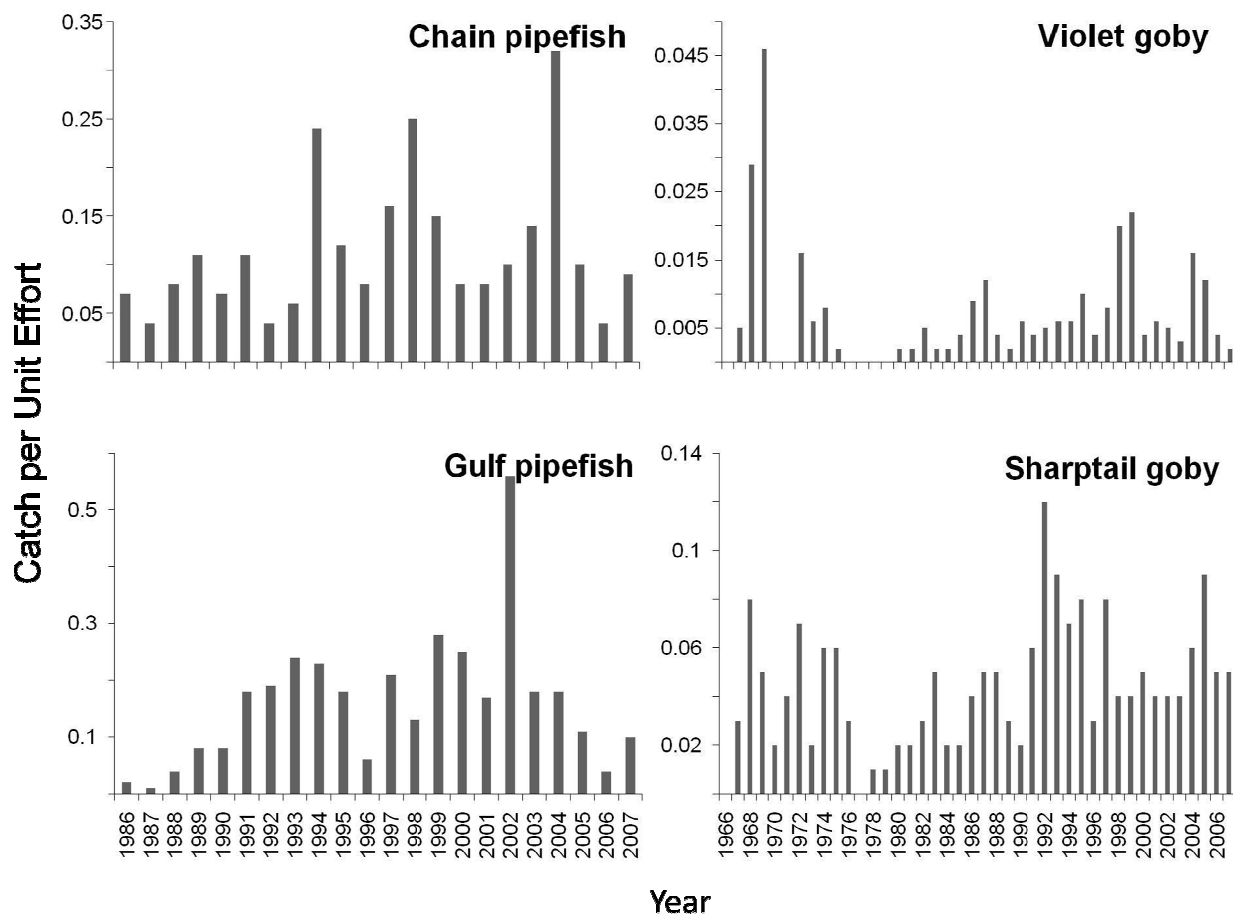


Figure 3.2 Annual catch per unit effort for two pipefish (1986-2007) and two goby species (1966-2007).

Abundance patterns across five five-year intervals for seines and nine five-year intervals for trawls showed some differences in abundance ($F \geq 6.65$, $df \geq 4$, 15115, $p \leq 0.0001$).

Abundances (Table 3.4) for chain pipefish were highest during the 1996-2000 interval and lowest during 1986-1990 and 2006-2007 intervals. For gulf pipefish, the abundances were highest during the 1991-2005 interval and lowest during the 1986-1990 and 2006-2007 intervals. For violet goby, the abundances were highest during the 1966-1970 interval and lowest during the 1976-1985 interval. For sharptail goby, the abundances were highest during the 1966-1970, 1991-1995 and 2001-2007 intervals and lowest during the 1976-1980 interval.

Table 3.3 Mean seasonal CPUE for the four species from the seine and trawl gear types were calculated for: spring (Mar-May), summer (Jun-Aug), fall (Sept-Nov), and winter (Dec-Feb). Different letters (read horizontally) indicate statistical differences in the CPUE across seasons within each species.

Common Name	CPUE			
	Spring	Summer	Fall	Winter
chain pipefish	0.11	0.16	0.11	0.09
gulf pipefish	0.19 a	0.21 a	0.12 b	0.17 ab
violet goby	0.01 a	0.01 b	0.00 b	0.00 b
sharptail goby	0.09 a	0.02 b	0.02 b	0.04 c

Table 3.4 Mean temporal CPUE for the four species from the seine and trawl gear types were calculated by five-year interval, except for the last interval which consists of two years. Different letters (read horizontally) indicate statistical differences in the CPUE across five-year intervals within each species.

Common Name	CPUE								
	1966-1970	1971-1975	1976-1980	1981-1985	1986-1990	1991-1995	1996-2000	2001-2005	2006-2007
chain pipefish					0.07 a	0.11 ab	0.14 b	0.14 b	0.07 a
gulf pipefish					0.04 a	0.20 b	0.19 b	0.24 b	0.07 a
violet goby	0.02 a	0.01 bc	0.00 c	0.00 c	0.01 bc	0.01 bc	0.01 ab	0.01 b	0.00 bc
sharptail goby	0.05 abc	0.05 ab	0.02 d	0.03 ad	0.04 a	0.08 c	0.05 ab	0.05 bc	0.05 abc

All species showed some significant differences in abundance across CSAs ($F \geq 9.98$ $df \geq 6$, 15113, $p \leq 0.0001$). Abundances (Table 3.5) for chain pipefish were highest for Caillou

stratum and were lowest for Chandeleur, Barataria, and Rockefeller Refuge strata. For gulf pipefish, abundances were highest for Mississippi River stratum and were lowest for Barataria, Terrebonne/Timbalier, Caillou, Atchafalaya, and Rockefeller Refuge strata. For violet goby, abundances were highest for Chandeleur, Mississippi River, Terrebonne/Timbalier, and Atchafalaya strata and were lowest for Barataria and Rockefeller Refuge strata. Abundances for Caillou stratum were not significantly different from any of the other CSAs. For sharptail goby, abundances were highest for Terrebonne/Timbalier stratum and were lowest for Mississippi River stratum.

Table 3.5 Mean CSA CPUE for the four species from the seine and trawl gear types. Different letters (read horizontally) indicate statistical differences in the CPUE across CSAs within each species.

Common Name	CPUE						
	Chandeleur stratum	Mississippi River stratum	Barataria stratum	Terrebonne/Timbalier stratum	Caillou stratum	Atchafalaya stratum	Rockefeller Refuge stratum
chain pipefish	0.09 a	0.15 b	0.04 a	0.15 b	0.22 c	0.17 b	0.02 a
gulf pipefish	0.30 a	0.87 b	0.02 c	0.05 c	0.03 c	0.03 c	0.00 c
violet goby	0.01 a	0.01 a	0.00 b	0.01 a	0.01 ab	0.01 a	0.00 b
sharptail goby	0.06 a	0.01 b	0.04 ac	0.12 d	0.05 a	0.02 bc	0.03 c

Size Distribution

Size distributions were analyzed to determine percentages of juvenile and adult individuals. Chain pipefish size ranged from 33 to 249 mm total length (TL) for the entire study period and the percentages of juveniles for each season (spring, summer, fall, and winter) were 94, 85, 88, and 82%, respectively. Gulf pipefish size ranged from 34 to 120 mm TL and the adult percentages for each season were 100, 88, 100, and 98 %, respectively. Violet goby sizes ranged from 26 to 550 mm TL and adult percentages for each season were 64, 83, 83, and 64 %, respectively. Sharptail goby sizes ranged from 5 to 520 mm TL and adult percentages for each season were 85, 95, 90, and 65%, respectively.

Habitat Suitability

Habitat suitability analyses for each species and gear type indicated strong patterns of selection for most species and variable combinations. For the pipefishes, the SOC species, chain pipefish, was compared to gulf pipefish based on the seine dataset. For chain pipefish, habitat suitability increased slightly with increasing temperatures (Fig. 3.3). For gulf pipefish, suitability did not show a strong pattern for temperature (Fig. 3.3). Salinity suitability for both species decreased with increasing salinities; however, chain pipefish had higher suitabilities for salinities less than 10 and gulf pipefish had higher suitability for salinities less than 12 (Fig. 3.4). For chain pipefish, habitat suitability for Secchi depths increased from 10 to 50 cm, was highest around 50 cm and then decreased (Fig 3.5). For gulf pipefish, the suitability increased with increasing Secchi depths (Fig 3.5).

For the gobies, the SOC species, violet goby, was compared to sharptail goby based on the trawl dataset. For temperature, violet goby had the highest suitability around 20 °C (Fig. 3.3). Suitability increased from 0 to 20 °C and then decreased. For sharptail goby, the highest suitability for temperature was around 22 °C (Fig. 3.3). Suitability increased from 0 to 22 °C and then decreased. For both violet goby and sharptail goby, habitat selections for salinity (Fig 3.4) and depths (Fig. 3.5) decreased as the salinity and Secchi depths increased.

Between Species Comparison

For both gear types, chi-square comparisons between patterns of resource availability and resource use of pipefishes and gobies for all three variables, as well as resource use between pipefishes and between gobies were statistically different with one exception. For the seine data (Table 3.6), temperatures used by chain pipefish ($\chi^2 = 126.3$, $df = 12$, $p \leq 0.0001$) were significantly higher than resource availability and gulf pipefish ($\chi^2 = 117.1$, $df = 12$, $p \leq 0.0001$)

used significantly lower temperatures than resource availability (Fig. 3.1). Chain pipefish used significantly higher temperatures than gulf pipefish ($\chi^2 = 170.5$, $df = 12$, $p \leq 0.0001$). For the trawl data, the temperatures used by both violet goby ($\chi^2 = 65.0$, $df = 12$, $p \leq 0.0001$) and sharptail goby ($\chi^2 = 205.4$, $df = 12$, $p \leq 0.0001$) were significantly lower than resource availability (Fig. 3.3). Both gobies used similar temperatures ($\chi^2 = 20.8$, $df = 12$, $p = 0.0538$).

For the seine data (Table 3.6), the salinities used by both chain pipefish ($\chi^2 = 393.0$, $df = 16$, $p \leq 0.0001$) and gulf pipefish ($\chi^2 = 1177.3$, $df = 16$, $p \leq 0.0001$) were significantly lower than resource availability (Fig. 3.4). Chain pipefish used higher salinities than gulf pipefish ($\chi^2 = 221.5$, $df = 16$, $p \leq 0.0001$). For the trawl data, salinities used by both gobies (violet goby: $\chi^2 = 70.7$, $df = 16$, $p \leq 0.0001$; sharptail goby: $\chi^2 = 121.0$, $df = 16$, $p \leq 0.0001$) were significantly lower than resource availability (Fig. 3.4). Violet goby used lower salinities than sharptail goby ($\chi^2 = 63.4$, $df = 16$, $p \leq 0.0001$).

For the seine data (Table 3.6), the sites used by both species (chain pipefish: $\chi^2 = 199.7$, $df = 11$, $p \leq 0.0001$; gulf pipefish: $\chi^2 = 224.1$, $df = 11$, $p \leq 0.0001$) were significantly less turbid than resource availability (Fig. 3.5). Chain pipefish used more turbid sites than gulf pipefish ($\chi^2 = 184.8$, $df = 11$, $p \leq 0.0001$). For the trawl data, sites used by both species (violet goby: $\chi^2 = 63.4$, $df = 11$, $p \leq 0.0001$; sharptail goby: $\chi^2 = 212.8$, $df = 11$, $p \leq 0.0001$) were significantly more turbid than resource availability (Fig. 3.5). Violet goby used more turbid sites than sharptail goby ($\chi^2 = 44.3$, $df = 11$, $p \leq 0.0001$).

DISCUSSION

Pipefishes

In pair-wise comparison, both pipefishes had significantly different suitability patterns for all three environmental variables. For both pipefishes, suitability patterns for salinity and

Secchi depth were strong and indicated that these variables affected habitat selection to some extent. Temperature suitabilities for both species showed weak patterns. In addition to the habitat suitabilities, the pipefishes had significantly different spatial patterns of abundances.

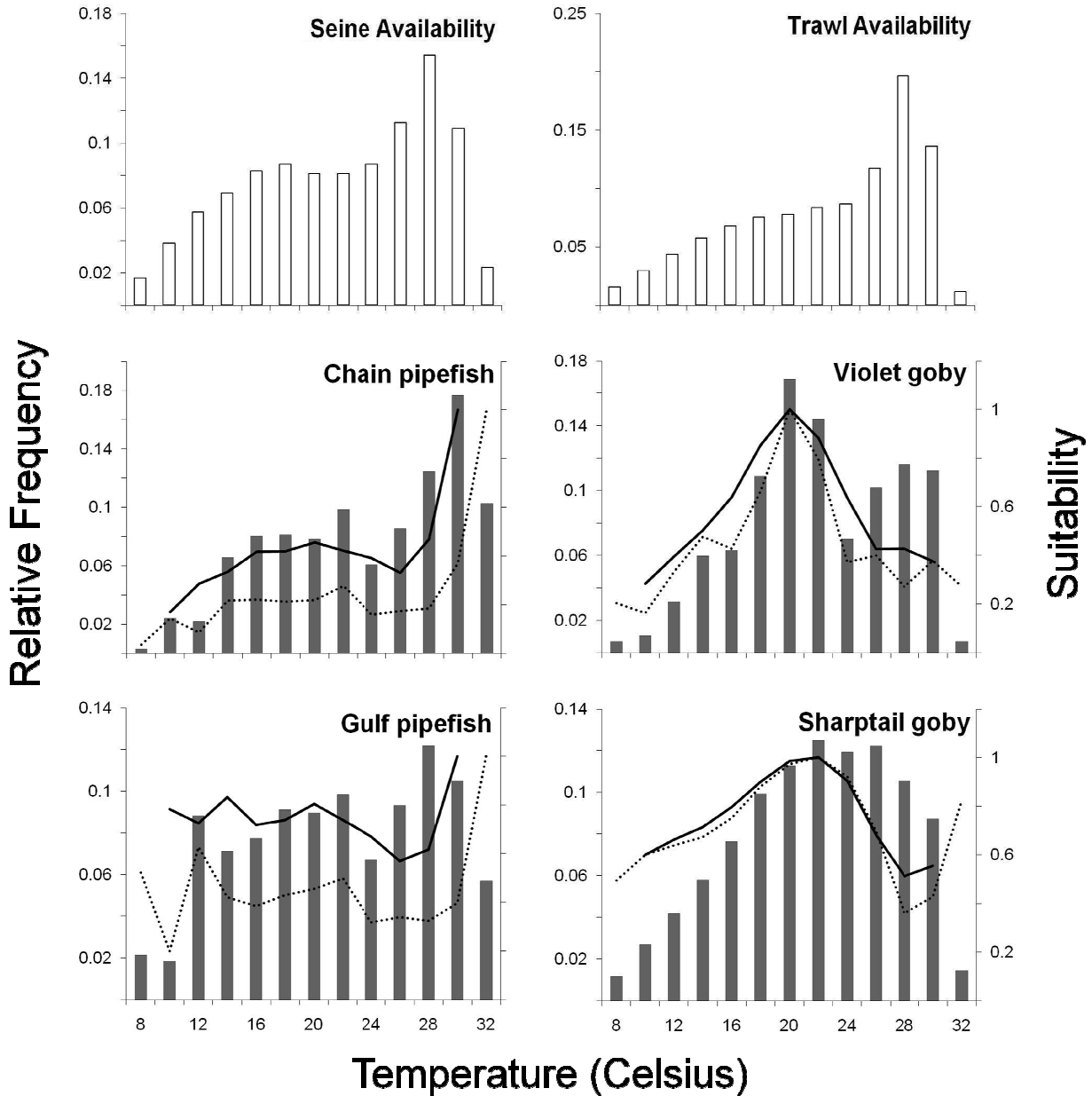


Figure 3.3 Habitat availability (open bars), use (closed bars), suitability patterns (dotted line), and 3-point moving suitability averages (solid line) along the temperature gradient for the two pipefishes and two gobies collected by LDWF using 15.2 m bag seine (left side) for years 1986 through 2007 and 4.9 m otter trawl (right side) for years 1966 through 2007, respectively.

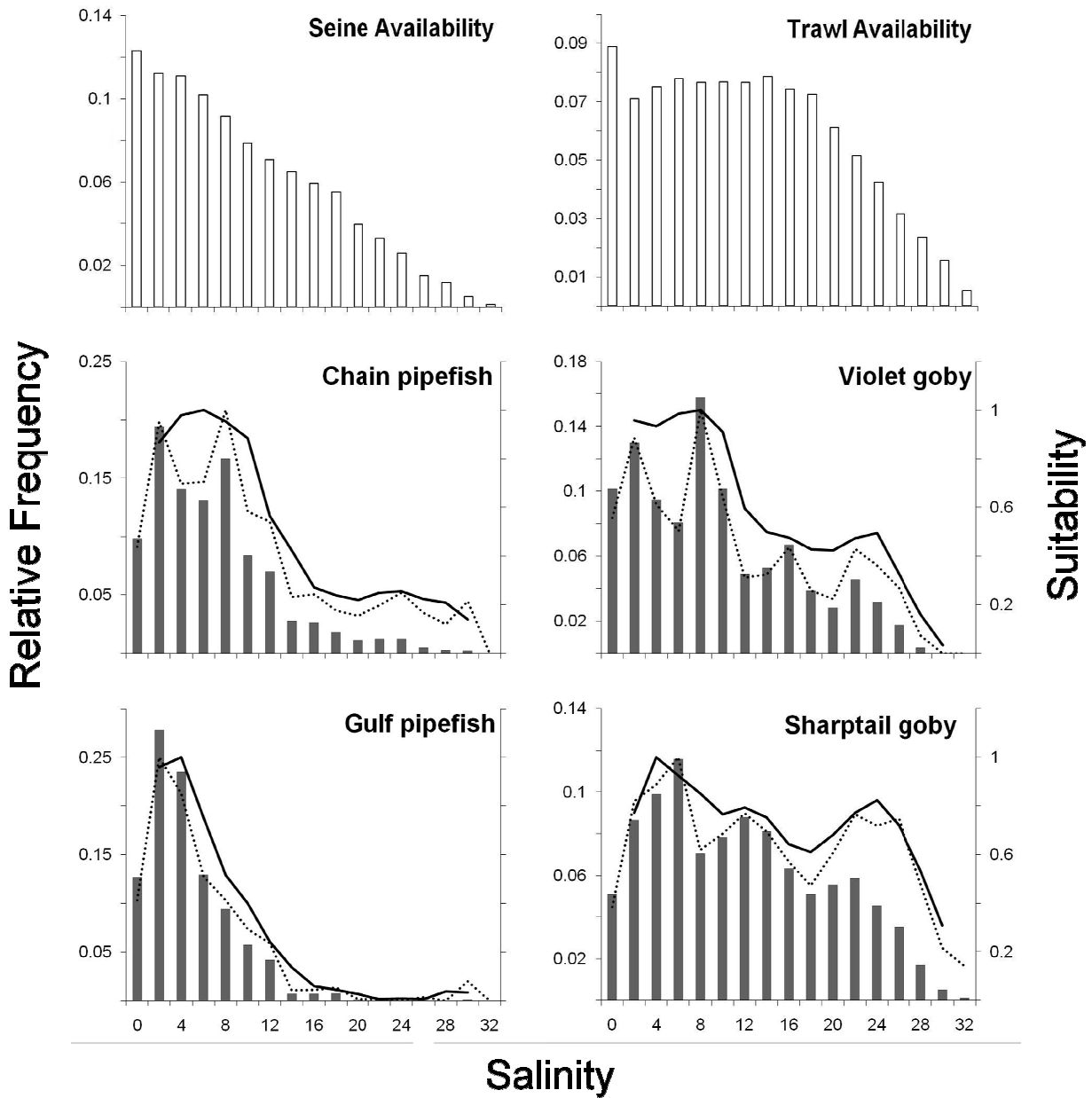


Figure 3.4 Habitat availability (open bars), use (closed bars), suitability patterns (dotted line), and 3-point moving suitability averages (solid line) along the salinity gradient for the two pipefishes and two gobies collected by LDWF using 15.2 m bag seine (left side) for years 1986 through 2007 and 4.9 m otter trawl (right side) for years 1966 through 2007, respectively.

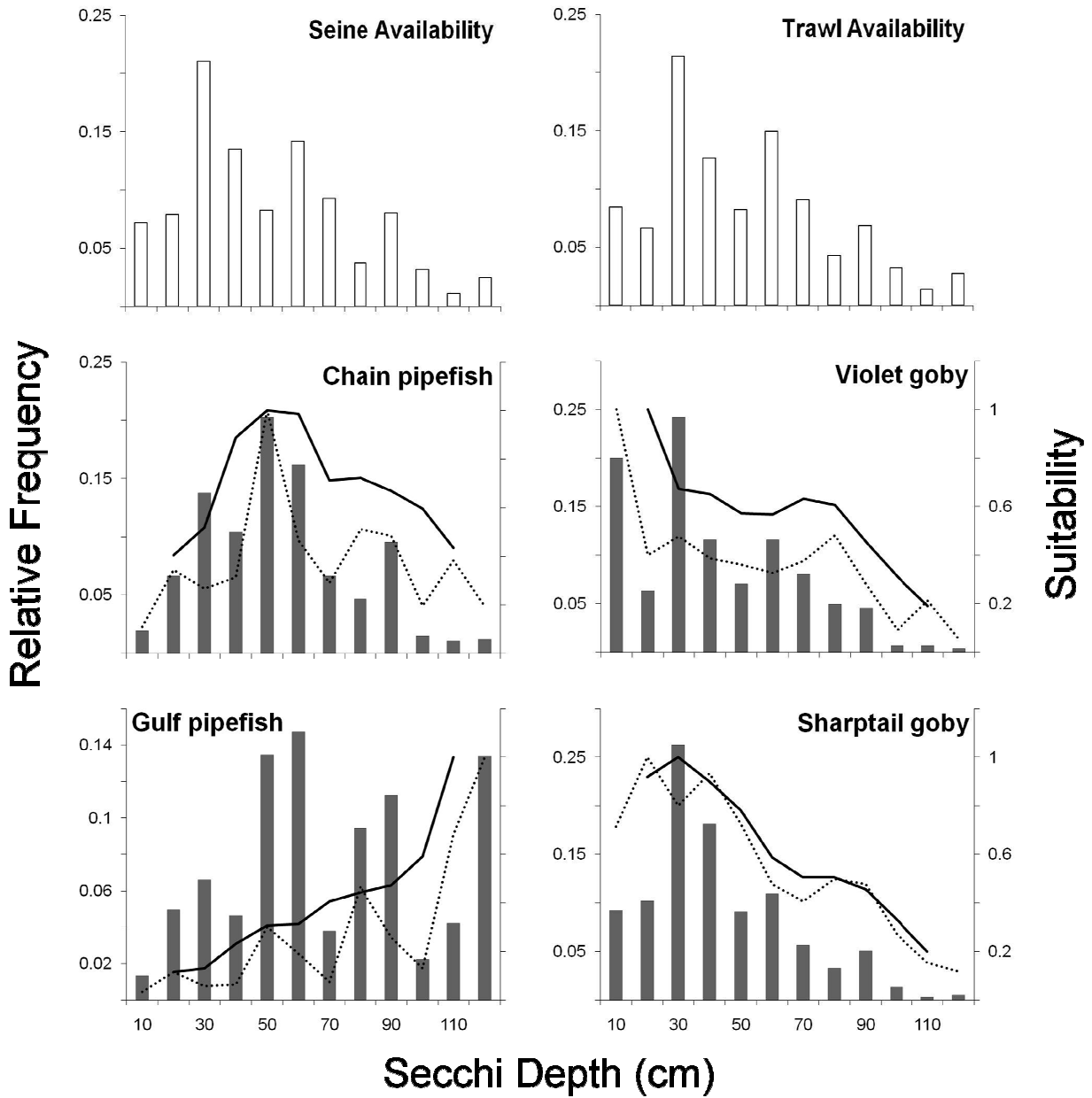


Figure 3.5 Habitat availability (open bars), use (closed bars), suitability patterns (dotted line), and 3-point moving suitability averages (solid line) along the Secchi depth gradient for the two pipefishes and two gobies collected by LDWF using 15.2 m bag seine (left side) for years 1986 through 2007 and 4.9 m otter trawl (right side) for years 1966 through 2007, respectively.

Table 3.6 Weighted means \pm 1 SE of temperature, salinity, and Secchi depth availabilities and uses by pipefishes and gobies captured in the both the seine and trawl gear types, respectively, in coastal Louisiana. For seine and trawl availability, *N* is the number of independent samples. For each species, *N* is the number of individuals.

Temperature	<i>N</i>	Mean \pm SE
Seine Availability	10292	21.8 \pm 0.06
chain pipefish	605	23.6 \pm 0.25
gulf pipefish	608	21.6 \pm 0.27
Trawl Availability	37730	22.7 \pm 0.03
violet goby	285	22.0 \pm 0.32
sharptail goby	1793	21.8 \pm 0.13
Salinity		
Seine Availability	10267	9.6 \pm 0.07
chain pipefish	615	6.9 \pm 0.22
gulf pipefish	605	5.0 \pm 0.20
Trawl Availability	37681	12.3 \pm 0.04
violet goby	285	9.37 \pm 0.42
sharptail goby	1793	11.8 \pm 0.18
Secchi depth		
Seine Availability	10292	50.8 \pm 0.27
chain pipefish	770	56.3 \pm 0.93
gulf pipefish	728	80.9 \pm 1.72
Trawl Availability	37730	50.8 \pm 0.14
violet goby	285	41.2 \pm 1.49
sharptail goby	1793	42.6 \pm 0.54

Chain pipefish had a weak pattern of temperature suitability with slightly higher selection centered around 14 to 18 °C (Fig. 3.3) and within the range of 12 to 31 °C reported by Dawson (1972) for the northern Gulf of Mexico. CPUEs across seasons were not significantly different (Table 3.3). Across the Gulf of Mexico, the highest abundances of chain pipefish occur from April to July (Dawson 1972, Kanouse et al. 2006, Wells and Rooker 2004), and the lowest abundances reported during February and December (Dawson 1972) in northern Gulf of Mexico estuaries. The higher percentage of juveniles during spring suggests that spawning occurs during

late summer and fall. The reproductive season for chain pipefish in Texas estuaries peaks during the late spring and early summer with a larger peak in juvenile abundance in August (Wells and Rooker 2004). Dawson (1972) also recorded the smallest individuals during May which suggests that spring is the peak for reproduction in Mississippi. Because information on the duration of brooding by males is scarce, it is difficult to determine an accurate time for egg fertilization. The patterns in temperature suitability do not appear to be a product of high abundances due to hatching, suggesting that temperature may be a general factor in habitat selection.

Gulf pipefish did not show strong selection for temperature (Fig. 3.3). They are found in temperatures ranging from 13 to 30 °C, and a population in Georgia withstands temperatures that drop to 5 °C for prolonged periods (Targett 1984). Highest abundances were found during winter, spring and summer. The increase in juveniles in summer may suggest that reproduction is slightly higher in spring, but the overall high numbers of adults suggests that spawning may occur throughout the year. Reproduction is reported throughout the year in Florida (Begovas and Wallace 1987, Hellier 1967); however, Joseph (1957) found a decline in reproductive activity in winter.

Chain pipefish had strong selection patterns for both salinity and Secchi depth (Figs 3.4 and 3.5). The optimal suitability range I found was much narrower than the salinity ranges recorded for the northern Gulf of Mexico from 13 to 36 (Dawson 1972) and for Brazil from 18 to 22 (Diaz-Ruiz et al. 2000). Patterns of selection for Secchi depths or other measurements of water clarity have not been reported in the literature.

Gulf pipefish showed strong selection for low salinities that decreased rapidly above 4, but tolerance ranged widely (Fig. 3.4) from 0 to 35 (Brown-Peterson et al. 1993, Diaz-Ruiz et al.

2000, Hubbs et al. 1991, Joseph 1957, Targett 1984, Whatley 1962). This species also spawns in fresh, brackish, and saline waters (Felly 1987, Hellier 1967, Quast and Howe 1980). Gulf pipefish also had strong and increasing selection for increasing Secchi depths (Fig. 3.5); however, measurements of water clarity have not been reported in the literature.

Although the two pipefishes are closely related and occupy similar habitat types, they had different patterns of habitat suitability and abundance. Both species also reported to have different reproductive seasons. The more common gulf pipefish used lower temperatures, lower salinities, and clearer water than the SOC chain pipefish. The limited number of gulf pipefish captured in this study may due to their higher selection for freshwater habitats than chain pipefish. The disappearance of brackish marshes in Louisiana may have a greater effect on chain pipefish populations than gulf pipefish due to the gulf pipefish use of freshwater habitats.

Gobies

The two goby species, violet goby and sharptail goby, had similar patterns of selection for temperature and Secchi depth. In addition, violet goby, the SOC, also showed a strong pattern for salinity selection, whereas, sharptail goby did not. Both goby species also had similar patterns of seasonal abundance. Data were insufficient to determine any spatial patterns of abundance for violet goby.

Violet goby habitat selection along the temperature gradient (Fig. 3.3) peaked near 20 °C and ranged from 8 to 32 °C. There is a limited amount of literature for this species. Dawson (1969) examined individuals from the northern Gulf of Mexico, but did not provide any insights into their temperature requirements. Seasonal abundance was highest during the spring (Table 3.3). The higher percentage of juveniles (< 100 mm SL) during winter and spring could be due to an increase in spawning during fall.

The sharptail goby temperature suitability pattern was similar to violet goby (Fig. 3.3). Larvae have been found in Chesapeake Bay, Virginia, in water temperatures around 13 °C (Olney and Boehlert 1988). I found the highest seasonal abundance was during spring. I found a higher percentage of juveniles (< 60 mm SL) in winter and spring, which suggests spawning season during fall and/or early winter. Warlen and Burke (1990) found sharptail goby larvae and juveniles in North Carolina from mid-November to late April and concluded that spawning occurs in fall and winter.

Both goby species had similar patterns of habitat selection which peaked for lower depths and decreased as water clarity increased. Use of Secchi depth and other measures of turbidity for the gobies has not been extensively reported. Violet goby had a stronger pattern of selection for lower salinity (Fig. 3.4) than sharptail goby. Dawson (1969) and Lee et al. (1980) found violet goby in salinities less than 1. Sharptail goby, on the other hand, is more euryhaline (Pezold 2004), but also occurs in low salinity areas (Dawson 1969).

There is only one apparent insight that can be learned from the data analyzed as to why the violet goby is listed as SOC and the sharptail goby is not. Both species occupy similar habitat types and have some similarities in their use of the three environmental gradients. They are also both in the center of their distribution ranges and are similar in size. Even though their temperature suitabilities were similar, the sharptail goby had a wider range of higher suitability. Both gobies used lower salinity and more turbid waters. The more common sharptail goby had more individuals caught during the study than violet goby. Both species had similar patterns of seasonal abundance and some overlap in spawning seasons. The violet goby, however, had a negative correlation with gulf WSE (Table 3.2), whereas, the sharptail goby did not.

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CHAPTER 4. COMPARING HABITAT SUITABILITY AND ABUNDANCE FOR THREE FUNDULID FISH SPECIES OF CONCERN, DIAMOND KILLIFISH, BAYOU KILLIFISH, AND SALTMARSH TOPMINNOW

RESULTS

Historical Trends

Annual catch per unit effort (CPUE) data were evaluated for each fundulid species to determine long-term trends in relative abundances (Fig. 4.1). The data for the fundulid species were from the seine dataset and covered the period from 1986-2007. Diamond killifish had higher abundances during years 1986-1987 and 1989-1991 and lower abundances in 1997-1999 and 2001-2002. Bayou killifish abundances were higher in 1987, 1990-1991 and 1995 and lower in 1992 and 2001. Saltmarsh topminnow had the lowest overall CPUEs for the fundulid species with higher abundances in 2006-2007 and lower abundances in 1987, 1989, 1992, 2000-2001 and 2004-2005. Linear regressions of CPUE on year were significant for diamond killifish and bayou killifish ($p \leq 0.002$), but not convincingly different from zero slopes (diamond killifish: $y = 1997.69 - 0.02x$, $r = 0.04$, slope $p \leq 0.0001$; bayou killifish: $y = 1997.67 - 0.02x$, $r = 0.02$, slope $p = 0.002$; saltmarsh topminnow: $p = 0.06$). Pearson's correlation (Table 4.1) did not show any significant correlations between the four climatic variables and the fundulid species, but did show a significant correlation between the annual abundances of diamond killifish and bayou killifish ($r = 0.67$, $p = 0.0006$).

Abundance Patterns

Temporal and spatial abundance patterns, estimated with CPUE, for all three fundulid species were significantly different ($F \geq 4.9$, $df \geq 3$, 15113, $p \leq 0.0006$) for seasons, five-year

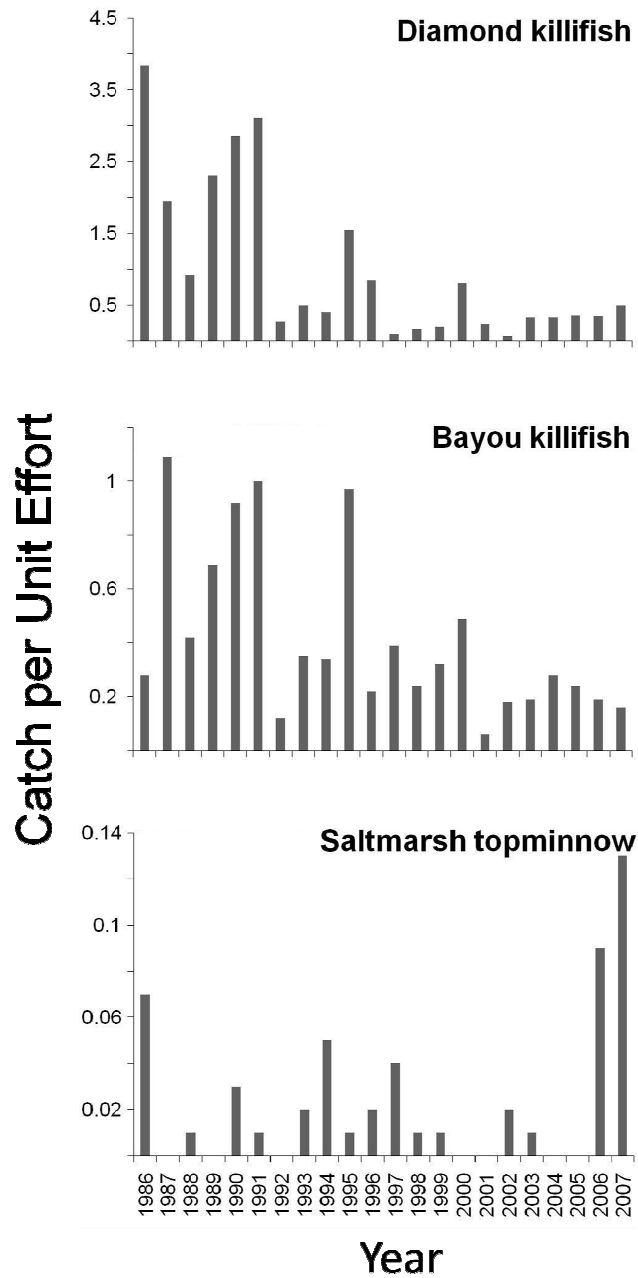


Figure 4.1 Annual catch per unit effort for three fundulid species for the entire study period (1986-2007).

Table 4.1 Pearson's correlation coefficients between the climatic variables and fundulid species. Bold coefficients indicate significantly correlated values ($p \leq 0.002$).

	River discharges	Surface water elevation	Oceanic Niño Index	Diamond killifish	Bayou killifish	Saltmarsh topminnow
Precipitation	0.33	0.22	0.32	0.01	0.09	-0.26
River discharges		0.33	0.04	0.00	-0.08	0.02
Surface water elevation			-0.01	0.24	0.32	-0.61
Oceanic Niño Index				0.05	0.17	0.12
Diamond killifish					0.67	0.11
Bayou killifish						-0.24

intervals, and CSAs (Table 4.2-4.4, respectively). Diamond killifish, bayou killifish, and saltmarsh topminnow had overall CPUEs of 0.84, 0.38, and 0.03, respectively.

One-way ANOVAs ($F \geq 7.8$, $df = 3$, 15116, $p \leq 0.0001$) found that significant differences in seasonal abundance patterns within each of the three fundulid SOC's (Table 4.2). Seasonal abundances peaked during winter for all three species, followed by fall. For bayou killifish, the abundances were lowest in spring and summer, and for saltmarsh topminnow, there were no individuals caught during summer.

Table 4.2 Mean seasonal CPUE for the three fundulid species was calculated for: spring (Mar-May), summer (Jun-Aug), fall (Sept-Nov), and winter (Dec-Feb). Different letters (read horizontally) indicate statistical differences in the CPUE across seasons for each species.

Common Name	CPUE			
	Spring	Summer	Fall	Winter
diamond killifish	0.56 a	0.08 b	0.67 a	1.97 c
bayou killifish	0.19 a	0.24 a	0.25 b	0.82 c
saltmarsh topminnow	0.02 ab	0.00 a	0.02 bc	0.06 c

Long-term changes in species abundance were tested with one-way ANOVAs ($F \geq 4.9$, $df = 4$, 15115, $p \leq 0.0006$) and differences in abundance among some of the five-year intervals were significant for all three species (Table 4.3). For both diamond killifish and bayou killifish the abundances were highest during the 1986-1990 interval and lowest during the 1996-2007 and

2001-2005 intervals, respectively. For saltmarsh topminnow, the highest abundances were during the 2006-2007 interval, and the lowest were during the 1986-2005 interval.

Table 4.3 Mean temporal CPUE for the three fundulid species were calculated in five-year intervals, except for the last interval which only consists of two years. Different letters (read horizontally) indicate statistical differences in the CPUE across five-year intervals for each species.

Common Name	CPUE				
	1986-1990	1991-1995	1996-2000	2001-2005	2006-2007
diamond killifish	2.39 a	1.08 b	0.42 c	0.26 c	0.43 c
bayou killifish	0.68 a	0.54 a	0.34 a	0.18 b	0.18 ab
saltmarsh topminnow	0.02 a	0.02 a	0.02 a	0.01 a	0.11 b

On a spatial scale, one-way ANOVAs ($F \geq 14.7$, $df = 6$, 15113, $p \leq 0.0001$) tested abundances across seven CSAs and found significant differences for all three fundulid SOC's (Table 4.4). The highest abundances for diamond killifish were in Terrebonne/Timbalier stratum, followed by Mississippi River stratum and the lowest in Chandeleur and Atchafalaya strata. For bayou killifish, the highest means were found in Mississippi River, Terrebonne/Timbalier, and Atchafalaya strata and the lowest in Barataria and Rockefeller Refuge strata. For saltmarsh topminnow, the highest abundances were in Terrebonne/Timbalier stratum and the lowest in Chandeleur, Barataria, and Atchafalaya strata where no individuals were caught.

Table 4.4 Mean CSA CPUE for the three fundulid species. Different letters (read horizontally) indicate statistical differences in the CPUE across CSAs for each species.

Common name	CPUE						
	Chandeleur stratum	Mississippi River stratum	Barataria stratum	Terrebonne/Timbalier stratum	Caillou stratum	Atchafalaya stratum	Rockefeller Refuge stratum
diamond killifish	0.16 a	1.94 b	0.65 ac	2.13 d	0.93 c	0.17 a	0.20 ac
bayou killifish	0.17 ab	1.13 c	0.02 a	0.81 c	0.20 b	0.50 c	0.05 a
saltmarsh topminnow	0.00 a	0.05 b	0.00 a	0.08 c	0.06 b	0.00 a	0.01 ab

Size Distributions

Size distributions for each species were analyzed to determine minimum and maximum size for the entire study period and percentages of adult individuals by seasons (spring, summer, fall and winter). Diamond killifish size ranged from 16 to 58 mm total length (TL) and adult percentages (> 19 mm SL) for spring and summer were 100 % and for fall and winter were 99 %. Bayou killifish size ranged from 19 to 107 mm TL and adult percentages (> 29 mm SL) for each season were 95, 60, 93, and 97 %, respectively. Saltmarsh topminnow size ranged from 21 to 61 mm TL and 100 % of all individuals were adults (> 21 mm SL).

Habitat Suitability

In habitat suitability graphs for temperature, salinity, and Secchi depth, all three fundulid species of concern (SOC) displayed some habitat selection for all three gradients. For temperature (Fig. 4.2), both diamond killifish and bayou killifish showed selection (i.e., high suitability) for lower temperatures, and suitability decreased with increasing temperature. Saltmarsh topminnow had the highest selection for temperatures less than 12 °C, and from 12 to 32 °C, suitability was low and slightly decreased with increasing temperature.

For salinity (Fig. 4.3), diamond killifish had the highest suitability values for salinities around 8. Habitat suitability increased from salinities of 0 to 8 and then decreased from 8 to 30. Both bayou killifish and saltmarsh topminnow showed a decrease in suitability with increasing salinity. Although the suitability for saltmarsh topminnow showed an overall decrease with increasing salinity, there appeared to be a bimodal pattern which may be related to seasonal patterns of recruitment.

Habitat suitability patterns for Secchi depth were erratic. For diamond killifish (Fig. 4.4), the highest suitability values were around 100 cm; suitability increased from 0 to 100 cm and

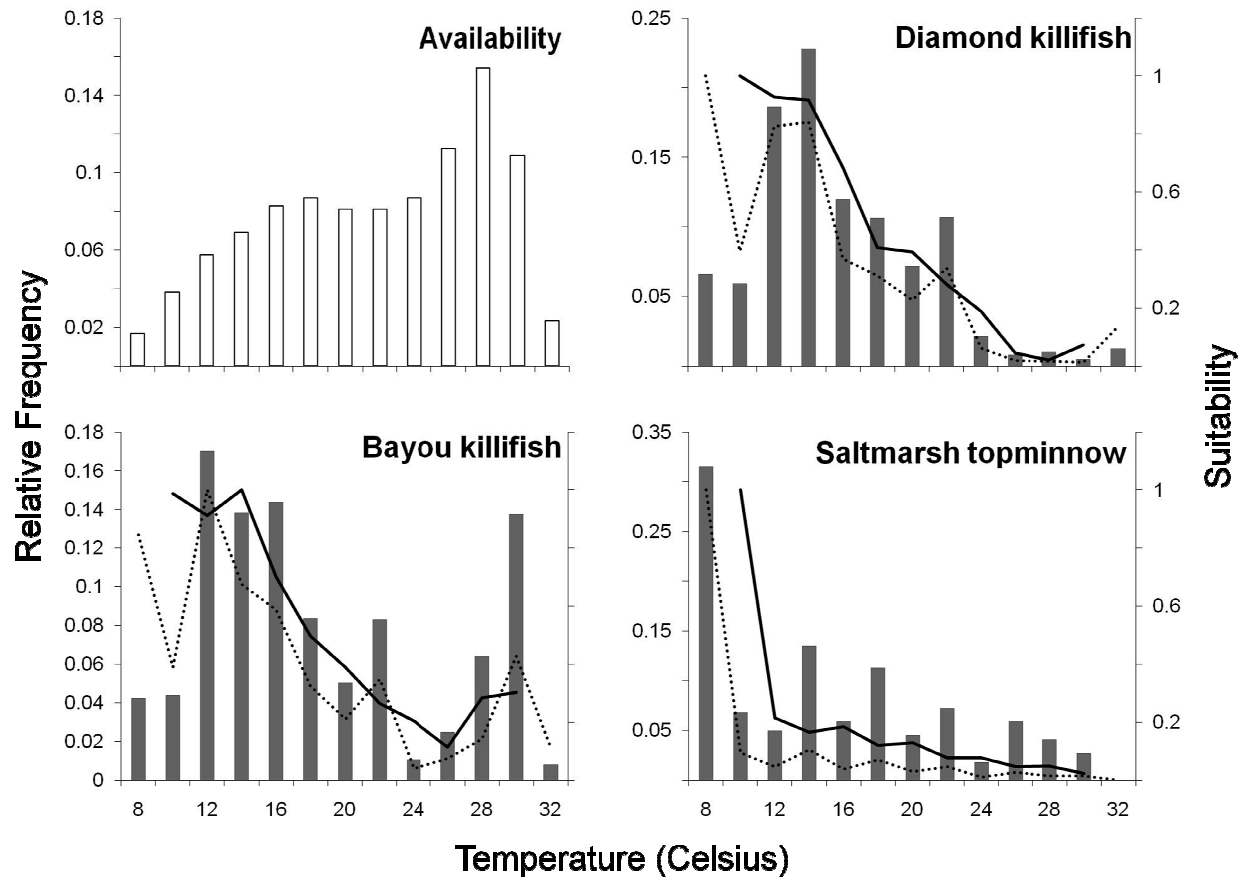


Figure 4.2 Habitat availability (open bars), use (closed bars), suitability patterns (dotted line), and 3-point moving suitability averages (solid line) along the temperature gradient for three fundulids collected by LDWF using 15.2 m bag seine for years 1986 through 2007.

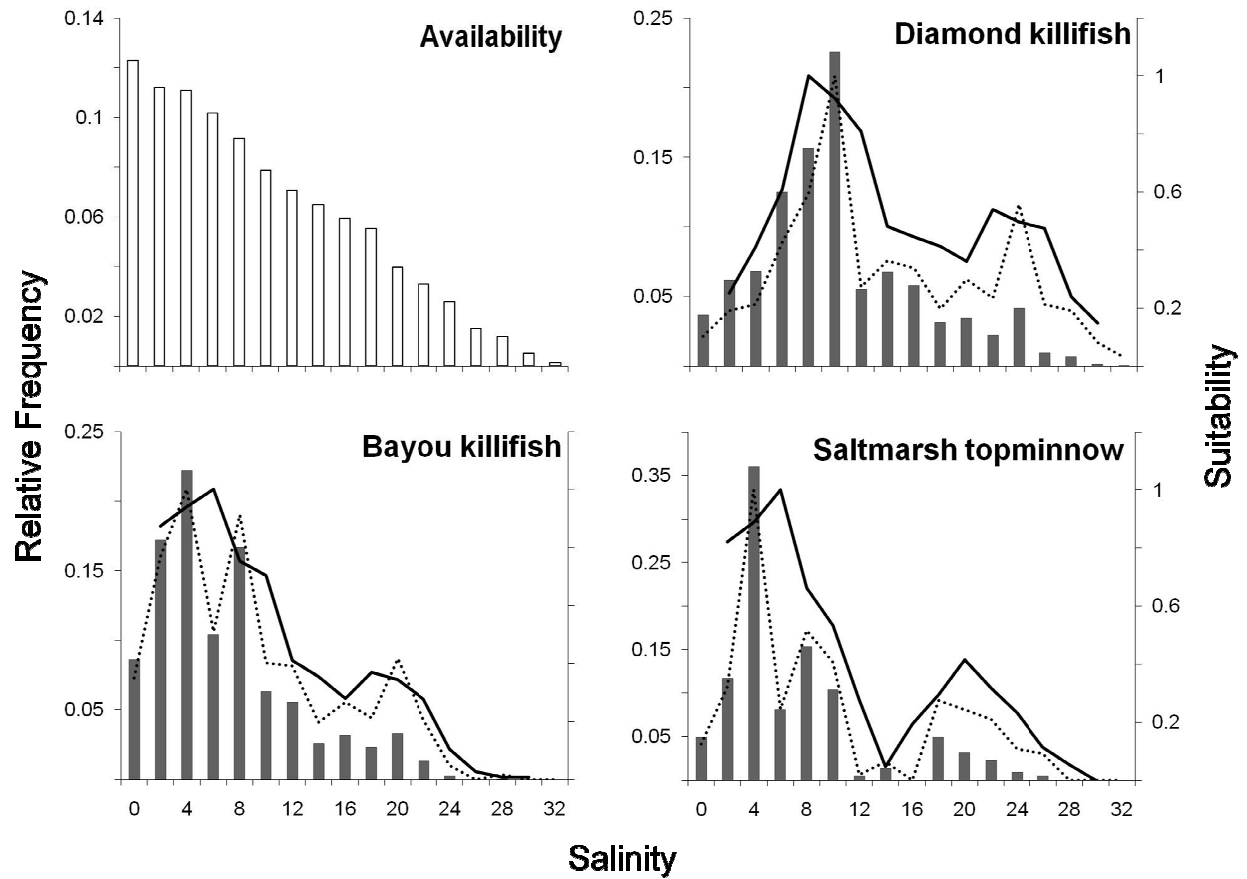


Figure 4.3 Habitat availability (open bars), use (closed bars), suitability patterns (dotted line), and 3-point moving suitability averages (solid line) along the salinity gradient for three fundulids collected by LDWF using 15.2 m bag seine for years 1986 through 2007.

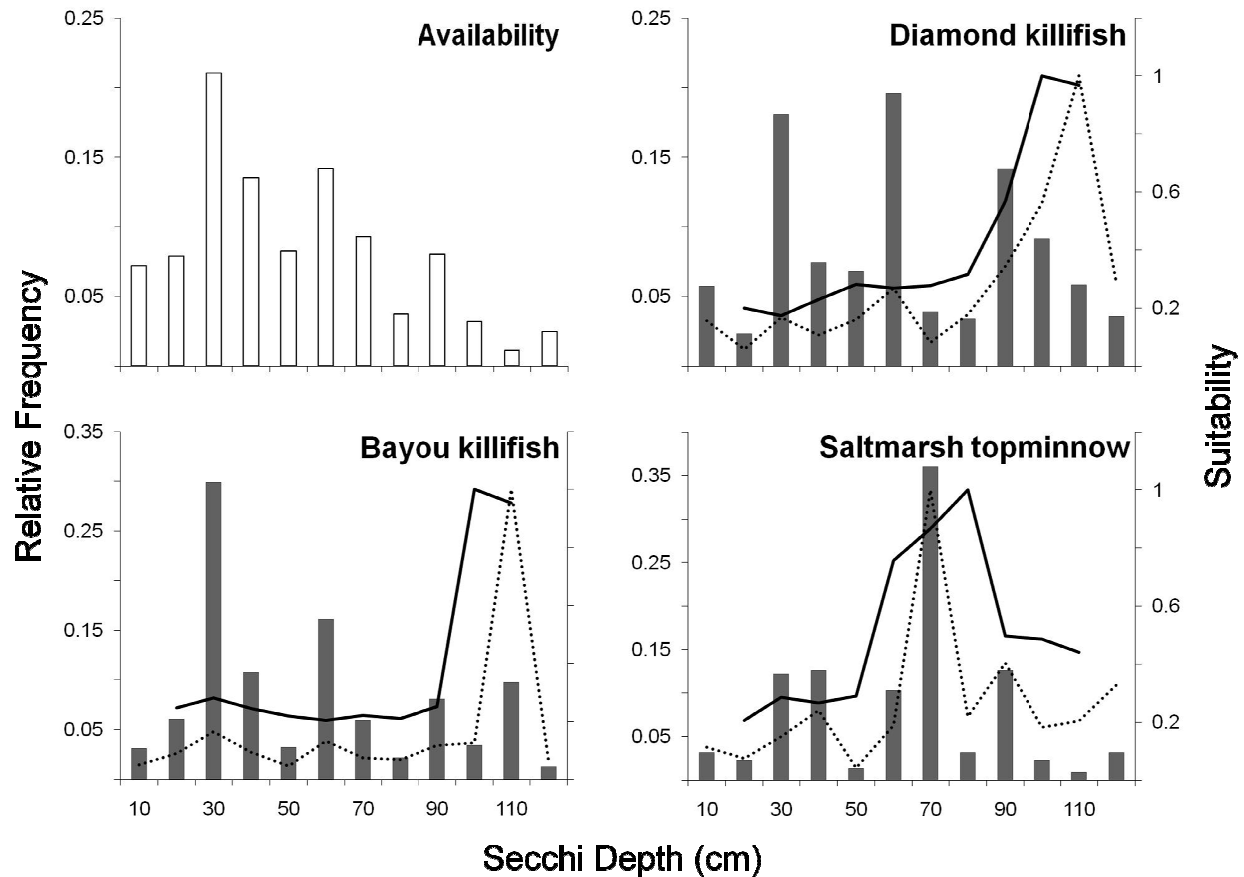


Figure 4.4 Habitat availability (open bars), use (closed bars), suitability patterns (dotted line), and 3-point moving suitability averages (solid line) along the Secchi depth gradient for three fundulids collected by LDWF using 15.2 m bag seine for years 1986 through 2007.

then decreased. Bayou killifish showed a flat response for most depths then rose around 100 cm.

For saltmarsh topminnow, habitat selection was higher for Secchi depths between 60 and 80 cm.

Between Species Comparisons

Chi-square (χ^2) tests of independence comparing resource availability and resource use distributions (Table 4.5), including contributions of individual cells to overall χ^2 values, found that all three variables showed overall significant differences for each of the fundulid SOC.

Temperatures used by all three species were significantly lower than resource availability

(diamond killifish: $\chi^2 = 5242.05$, $df = 12$, $p \leq 0.0001$; bayou killifish: $\chi^2 = 1666.09$, $df = 12$, $p \leq 0.0001$; saltmarsh topminnow: $\chi^2 = 911.35$, $df = 12$, $p \leq 0.0001$). Bayou killifish used

temperatures significantly higher than diamond killifish ($\chi^2 = 1728.31$, $df = 12$, $p \leq 0.0001$) and saltmarsh topminnow ($\chi^2 = 354.32$, $df = 12$, $p \leq 0.0001$). Diamond killifish used slightly higher temperatures than saltmarsh topminnow ($\chi^2 = 328.11$, $df = 12$, $p \leq 0.0001$).

Table 4.5 Weighted means \pm 1 SE of temperature, salinity, and Secchi depth availabilities and uses by the three fundulid species captured in the 15.2 m bag seine in coastal Louisiana, 1986-2007. *N* is the number of independent samples for the availability data and the number of individuals captured for the three species.

	Total N	Mean \pm SE
Temperature		
Available	10553	21.8 \pm 0.06
diamond killifish	9326	15.7 \pm 0.05
bayou killifish	4457	18.5 \pm 0.10
saltmarsh topminnow	222	15.0 \pm 0.45
Salinity		
Available	10526	9.6 \pm 0.07
diamond killifish	9326	6.8 \pm 0.08
bayou killifish	4452	13.2 \pm 1.77
saltmarsh topminnow	222	7.0 \pm 0.38
Secchi Depth		
Available	10553	50.8 \pm 0.27
diamond killifish	9326	55.0 \pm 0.45
bayou killifish	4457	64.0 \pm 8.57
saltmarsh topminnow	222	62.5 \pm 1.65

Salinities (Table 4.5) used by bayou killifish were significantly higher than resource availability ($\chi^2 = 1059.77$, $df = 16$, $p \leq 0.0001$), whereas, salinities used by both diamond killifish ($\chi^2 = 1796.80$, $df = 16$, $p \leq 0.0001$) and saltmarsh topminnow ($\chi^2 = 185.66$, $df = 16$, $p \leq 0.0001$) were significantly lower than resource availability. Both diamond killifish ($\chi^2 = 1979.75$, $df = 16$, $p \leq 0.0001$) and saltmarsh topminnow ($\chi^2 = 80.92$, $df = 16$, $p \leq 0.0001$) used salinities significantly lower than bayou killifish. Diamond killifish used a lower salinities than saltmarsh topminnow ($\chi^2 = 322.54$, $df = 16$, $p \leq 0.0001$).

Secchi depths (Table 4.5) used by all three fundulid species were significantly greater than resource availability (diamond killifish: $\chi^2 = 1686.46$, $df = 11$, $p \leq 0.0001$; bayou killifish:

$\chi^2 = 1272.49$, $df = 11$, $p \leq 0.0001$; saltmarsh topminnow: $\chi^2 = 211.91$, $df = 11$, $p \leq 0.0001$).

Both diamond killifish ($\chi^2 = 871.56$, $df = 11$, $p \leq 0.0001$) and saltmarsh topminnow ($\chi^2 = 537.61$, $df = 11$, $p \leq 0.0001$) used significantly less turbid waters than bayou killifish. Bayou killifish used significantly more turbid waters than saltmarsh topminnow ($\chi^2 = 325.54$, $df = 11$, $p \leq 0.0001$).

DISCUSSION

All three species had strong patterns of habitat selection and abundance with one exception. Selection patterns for temperature and salinity were strong for all three species, but patterns of Secchi depth selection were only strong for diamond killifish and bayou killifish, and apparently did not influence the distribution of saltmarsh topminnow. The temporal abundance patterns of all three species peaked in the winter season and all three SOC's had peak abundances in the central CSAs.

Even though all three species had significantly different patterns of temperature suitability, it was higher for lower temperatures and decreased with increasing temperatures (Fig. 4.2). Hastings and Yerger (1971) did not describe temperature preferences and suggested that temperature was not an important factor for diamond killifish habitat selection across northern Gulf of Mexico estuaries; however, their observations were during winter and spring only when temperatures ranged from 20 to 29 °C. Nordlie (2006) and Simpson and Gunter (1956) reported finding bayou killifish in temperatures ranging from 17 to 35 °C in the northern Gulf of Mexico. Temperatures less than 12 °C had higher suitability for saltmarsh topminnow. Working in systems across the northern Gulf of Mexico, Lopez et al. (2010) and Peterson et al. (2003) found that saltmarsh topminnows select temperatures greater than 15 °C. Temperature can affect growth of fishes (Jobling 1981) with individuals living near optimal temperatures having higher rates than individuals living outside the optimal range. Temperature can also act as a resource

(Magnuson et al. 1979) and affect site selection (*sensu* Hulbert 1981). The strong patterns of suitability for low temperatures could indicate that temperature is an important factor for habitat selection.

All three fundulid SOC's are found in freshwater, brackish and saltmarsh habitat types (Hardy 1980, Hastings and Yerger 1971) across a broad range of salinities. Nevertheless, Peterson et al. (2003) assert that salinity is an important factor in the distribution and abundance for all three species. Diamond killifish showed selection in Louisiana for salinities around 8 (Fig. 4.3). Minello and Rozas (2002) found diamond killifish in salinities ranging from 11 to 20 in Texas. Nordlie (1987) found them in intermediate salinities from 19 to 30, and lab experiments at 20 ± 1 °C demonstrated a salinity tolerance up to 95. Hastings and Yerger (1971) do not believe that salinity is an important factor for diamond killifish habitat selection due to their abundance in a wide range of salinities. In this study, both bayou killifish and saltmarsh topminnow showed a decrease in suitability with increasing salinity (Fig. 4.2). Bayou killifish occurs in low to medium salinities ranging from 0 to 48, and can survive in fresh water for at least two months (Griffith 1974, Gunter 1950, Miller and Guillory 1980). Saltmarsh topminnow occur in salinities ranging from 1 to 20 (Thompson 1999), and in salinities less than 16 (Lopez et al. 2010, Peterson et al. 2003).

Patterns of selection for Secchi depth and other measures of water clarity have not been extensively studied for the SOC's. Both diamond killifish and bayou killifish had weak Secchi depth suitability patterns (Fig. 4.4). Hastings and Yerger (1971) found that diamond killifish are often abundant in vegetation and concluded that vegetation seemed to be an important factor in determining distribution and abundance. Saltmarsh topminnow also had a weak pattern of suitability for Secchi depth (Fig. 4.4). Lopez et al. (2010) only found saltmarsh topminnow in

waters where the turbidity was less than 30 NTU. Several studies have linked vegetation to increased water clarity (Horppila and Nurminen 2001, Scheffer 1999). This suggests that these species may have stronger selection for habitat types with vegetation for regions along a turbidity gradient.

All three SOC's had higher abundances during winter which is concordant with higher suitabilities for lower temperatures (Table 4.2). Rozas and Reed (1993) found that diamond killifish had higher abundances during fall, and Milleno and Rozas (2002) observed similar abundances between spring and fall. The spawning season for diamond killifish is from February through September (Hastings and Yerger 1971, Kilby 1955). The spawning season for bayou killifish occurs during fall and winter (Nordlie 2006, Simpson and Gunter 1956) which coincides with the higher abundances during winter and higher suitability for lower temperatures. Thompson (1999) found that saltmarsh topminnow breeds from March through August which is similar to the spawning season of diamond killifish. This suggests that spawning occurs during late fall and early winter, and higher abundances in fall could be due to the previous year's offspring recruiting to the gear. High abundances in winter may result from individuals being moved to the gear by frequent frontal passages with north winds that drive populations out of marshes and intertidal ponds (Dagg 1988).

Abundances of the three SOC's were significantly higher in central Louisiana (Terrebonne/Timbalier stratum) and significantly lower in western Louisiana (Rockefeller Refuge stratum). Future research is needed to determine factors responsible for increased abundances in Terrebonne/Timbalier stratum and decreased abundances in Rockefeller Refuge stratum.

The fundulid SOC's had strong patterns of temperature and salinity suitabilities. They selected lower temperatures and a wide range of salinities. None of the species showed strong patterns of Secchi depth suitability. All three species had higher seasonal abundances in winter and higher spatial abundances in central Louisiana (Terrebonne/Timbalier stratum). Annual abundances of diamond killifish were positively correlated with those of bayou killifish (Table 4.1), which suggests the two species are affected similarly with changes in environmental conditions.

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CHAPTER 5. HABITAT SUITABILITY AND ABUNDANCE OF TWO CANDIDATE SPECIES OF CONCERN, ATLANTIC THREADFIN AND SOUTHERN PUFFER

RESULTS

Historical Trends

Trends in relative abundance (catch per unit effort, CPUE) were used to identify species that should be considered as candidates for listing as species of concern (SOC). Both seine and trawl databases were evaluated, but the seine record was insufficient to provide conclusive information. After reviewing changing patterns of abundance in the trawl database over the study period, two species, southern puffer and Atlantic threadfin, were identified as potential SOCs based on noticeable decreases in abundances over the 41 year period (Fig. 5.1).

Abundances for southern puffer were highest from 1966 to 1973 with all values greater than 0.04. From 1973 to 1989, abundances ranged from 0 to 0.04. After 1989, CPUE was near zero except for 2006 when it reached 0.01. For Atlantic threadfin, abundance was highly variable prior to 1992, and ranged from near zero to greater than 0.15; however, after 1992, CPUEs were near zero for all years except 1997 when it reached 0.02. Linear regressions of CPUE on year were significant for both species (southern puffer: $y = 1991.16 - 0.27x$, $r = 0.05$, slope $p \leq 0.0001$; Atlantic threadfin: $y = 1991.16 - 0.27x$, $r = 0.10$, slope $p \leq 0.0001$). Pearson's correlations (Table 5.1) only showed one significant negative correlation between the annual abundance of Atlantic threadfin and gulf water surface elevation ($r = -0.82$, $p \leq 0.0001$).

Abundance Patterns

Changing patterns of relative abundances based on CPUE for the two SOC candidates were evaluated for the 41 year study period, seasons, five-year intervals, and across coastal study areas (CSAs) (Table 5.2-5.4). The CPUEs for the entire study period for Atlantic threadfin and

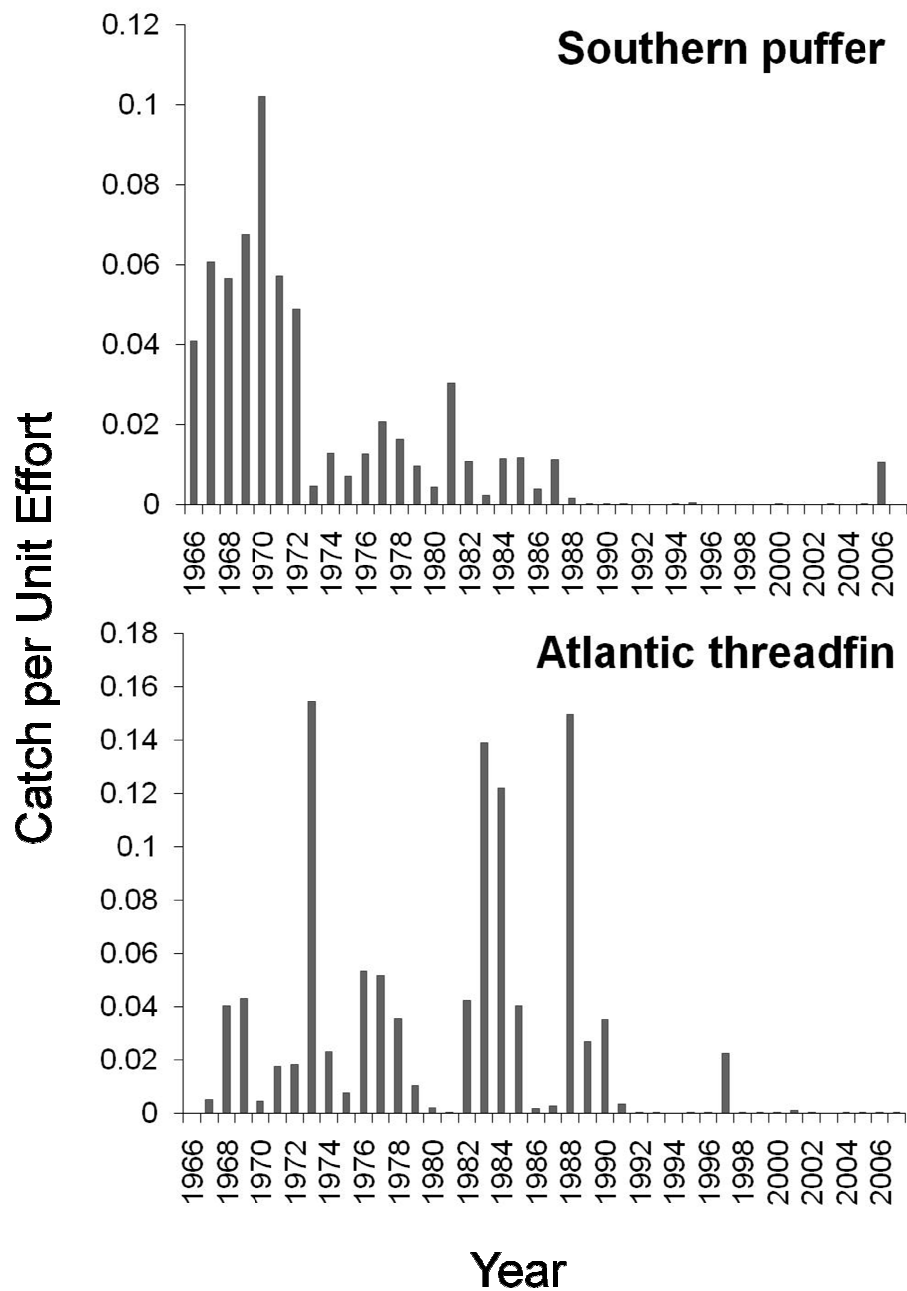


Figure 5.1 Annual catch per unit effort for southern puffer and Atlantic threadfin for the entire study period (1966-2007).

Table 5.1 Pearson's correlation coefficients between the climatic variables and candidate species. Bold coefficients indicate significantly correlated values ($P \leq 0.003$).

	River discharges	Surface water elevation	Oceanic Niño Index	Southern puffer	Atlantic threadfin
Precipitation	0.33	0.22	0.32	-0.30	-0.06
River discharges		0.33	0.04	-0.32	-0.14
Surface water elevation			-0.01	-0.11	-0.81
Oceanic Niño Index				-0.09	-0.10
Southern puffer					-0.14

southern puffer were 2.13 and 0.27, respectively. All within species comparisons were significant (one-way ANOVAs, $F \geq 77.7$, $df \geq 3$, 51893, $p \leq 0.0001$). Seasonal abundance patterns differed within both species (one-way ANOVAs, $F \geq 100.3$, $df = 3$, 51898, $p \leq 0.0001$). Atlantic threadfin had the highest abundance in spring followed by summer, fall, and winter, respectively. For southern puffer, seasonal abundances peaked during summer, followed by fall, spring, and winter, respectively.

Table 5.2 Mean seasonal CPUE for the two SOC candidate species was calculated for: spring (Mar-May), summer (Jun-Aug), fall (Sept-Nov), and winter (Dec-Feb). Different letters (read horizontally) indicate statistical differences in the CPUE across seasons for each species.

Common Name	CPUE			
	Spring	Summer	Fall	Winter
Atlantic threadfin	5.44 a	1.62 b	0.09 c	0.03 c
southern puffer	0.11 a	0.51 b	0.30 c	0.09 a

Abundances (Table 5.3) over five-year intervals for Atlantic threadfin were significantly different (one-way ANOVA, $F = 427.3$, $df = 4$, 51893, $p \leq 0.0001$) and highest during the 1981-1985 interval. Abundance decreased dramatically during the 1991-2007 intervals. For southern puffer, abundances were significantly different (one-way ANOVA, $F = 452.4$, $df = 4$, 51893, $p \leq 0.0001$). The highest abundance occurred during the 1966-1970 interval and generally decreased with time.

Table 5.3 Mean overall and temporal CPUE for the two SOC candidate species were calculated by five-year intervals, except for the last which consisted of two years. Different letters (read horizontally) indicate statistical differences in the CPUE across five-year intervals for each species.

Common Name	CPUE								
	1966-1970	1971-1975	1976-1980	1981-1985	1986-1990	1991-1995	1996-2000	2001-2005	2006-2007
Atlantic threadfin	2.03 a	4.42 b	1.82 a	8.98 c	3.11 d	0.03 e	0.20 e	0.01 e	0.00 e
southern puffer	2.25 a	0.80 b	0.34 c	0.56 c	0.17 b	0.01 d	0.00 d	0.00 d	0.00 d

One-way ANOVAs ($F \geq 77.7$, $df = 6$, 51895, $p \leq 0.0001$) tested spatial abundances for both species and found significant differences among CSAs. Abundances (Table 5.4) for Atlantic threadfin were highest in Caillou stratum and lowest in Chandeleur, Mississippi River, and Atchafalaya strata. The abundances for southern puffer were highest in Barataria and Rockefeller Refuge strata and lowest in Terrebonne/Timbalier and Caillou strata.

Table 5.4 Mean CSA CPUE for two SOC candidate species. Different letters (read horizontally) indicate statistical differences in the CPUE across CSAs for each species.

Common name	CPUE						
	Chandeleur stratum	Mississippi River stratum	Barataria stratum	Terrebonne/Timbalier stratum	Caillou stratum	Atchafalaya stratum	Rockefeller Refuge stratum
Atlantic threadfin	1.34 a	0.82 b	1.91 b	2.82 c	3.86 d	1.11 ab	3.08 c
southern puffer	0.54 a	0.50 b	0.31 a	0.07 cd	0.00 c	0.13 d	0.51 b

Size Distributions

Size distributions were analyzed for both candidate species to determine minimum and maximum sizes for the entire study period and percentages of juveniles for each season (spring, summer, fall, and winter). Atlantic threadfin size ranged from 10 to 230 mm total length (TL) and percentages of juveniles for each season were 98, 60, 36, and 81 %, respectively. Southern puffer size ranged from 5 to 245 mm TL and juvenile percentages exceeded 99 % for all seasons.

Habitat Suitability

Both candidate species had strong patterns of habitat suitability for all three environmental variables. For temperature (Fig. 5.2), the suitability for southern puffer increased

with increasing temperature. For Atlantic threadfin, temperature suitability was highest around 22 °C, and then decreased as the temperature increased beyond 22 °C. For southern puffer, salinities around 10 had the highest habitat suitability (Fig. 5.3). Suitability was low for salinities less than 10 and decreased with increasing salinity. For Atlantic threadfin, salinities ranging from 16 through 26 showed the highest suitability. Suitability increased from salinities 0 to 16 and then decreased with increasing salinities beyond 26. For Secchi depth (Fig. 5.4), the suitability for both southern puffer and Atlantic threadfin peaked at around 30 cm and then decreased with increasing depths.

Between Species Comparisons

Chi-square tests of independence were used to compare patterns of resource use with resource availability and to compare between the candidate species (Table 5.5). For temperature, both southern puffer ($\chi^2 = 1643.0$, $df = 12$, $p \leq 0.0001$) and Atlantic threadfin ($\chi^2 = 23707.5$, $df = 12$, $p \leq 0.0001$) used temperatures that were significantly higher than the resource availability, and southern puffer used temperatures significantly higher than Atlantic threadfin ($\chi^2 = 5168.0$, $df = 12$, $p \leq 0.0001$).

Atlantic threadfin ($\chi^2 = 12429.5$, $df = 16$, $p \leq 0.0001$) used salinities significantly higher than resource availability and higher than salinities used by southern puffer ($\chi^2 = 3169.1$, $df = 16$, $p \leq 0.0001$). Southern puffer used salinities significantly higher than the resource availability ($\chi^2 = 2182.7$, $df = 16$, $p \leq 0.0001$).

For Secchi depth, both southern puffer ($\chi^2 = 1182.0$, $df = 11$, $p \leq 0.0001$) and Atlantic threadfin ($\chi^2 = 5968.2$, $df = 11$, $p \leq 0.0001$) used sites that were significantly more turbid than the resource availability. Secchi depths used by southern puffer were also significantly more turbid than sites used by Atlantic threadfin ($\chi^2 = 407.5$, $df = 11$, $p \leq 0.0001$).

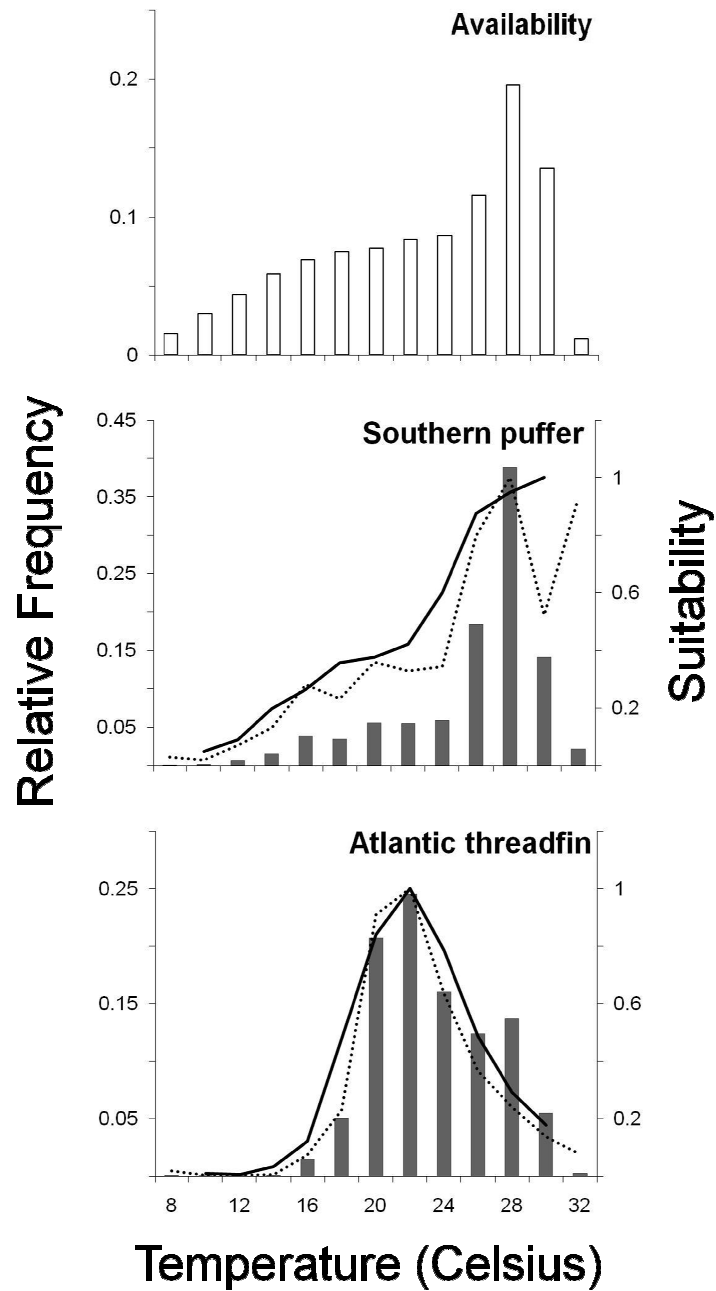


Figure 5.2 Habitat availability (open bars), use (closed bars), suitability patterns (dotted line), and 3-point moving suitability averages (solid line) along the temperature gradient for two SOC candidate species collected by LDWF using 4.9 m bag seine for years 1966 through 2007.

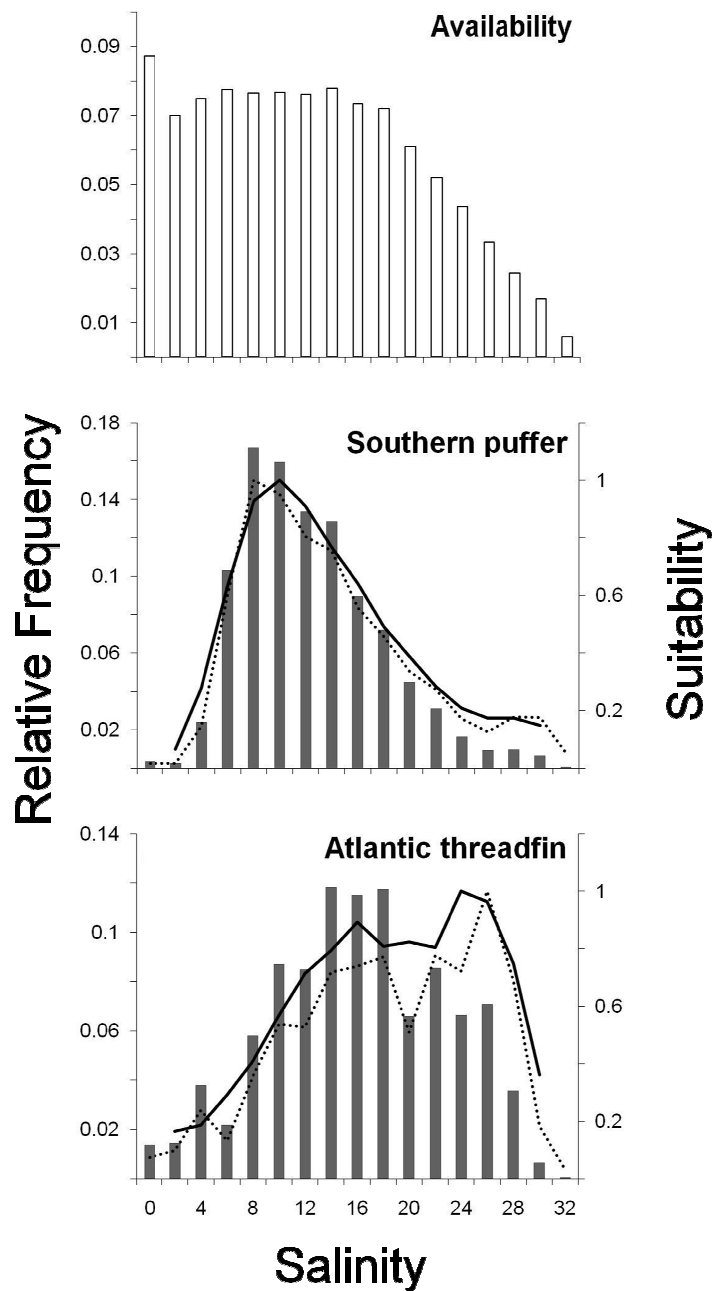


Figure 5.3 Habitat availability (open bars), use (closed bars), suitability patterns (dotted line), and 3-point moving suitability averages (solid line) along the salinity gradient for two SOC candidate species collected by LDWF using 4.9 m bag seine for years 1966 through 2007.

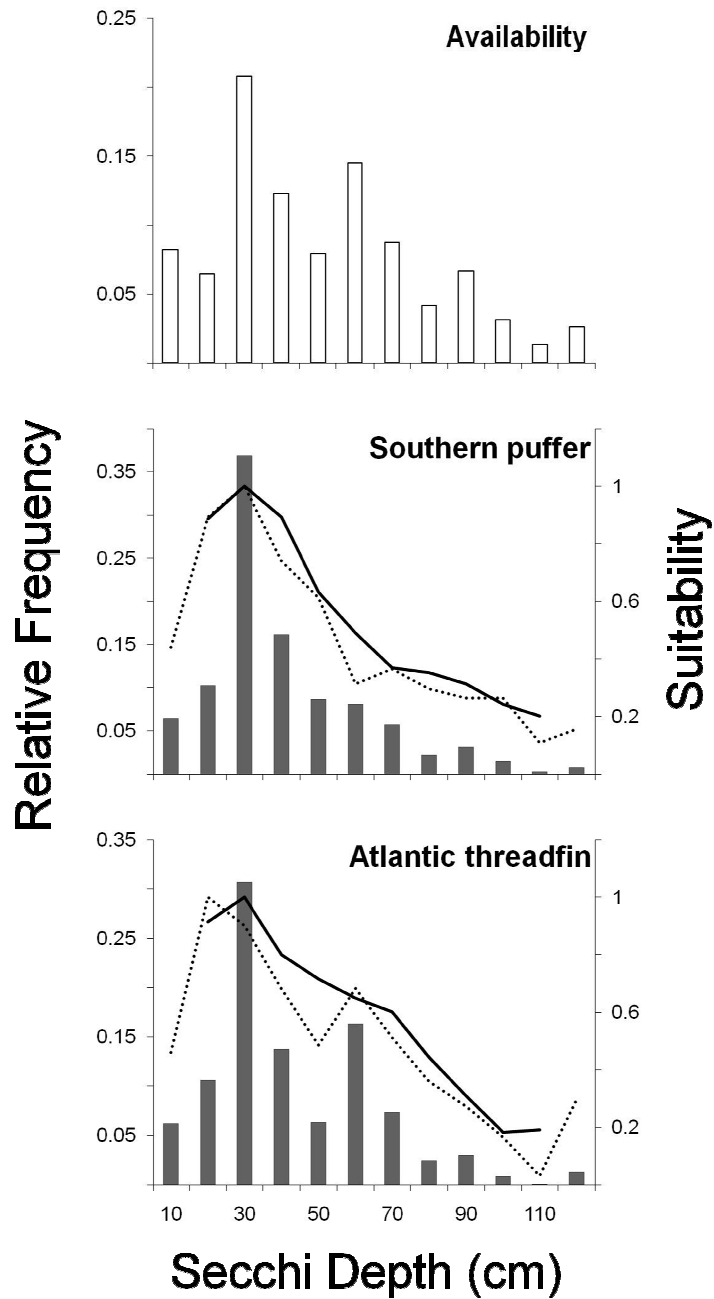


Figure 5.4 Habitat availability (open bars), use (closed bars), suitability patterns (dotted line), and 3-point moving suitability averages (solid line) along the Secchi depth gradient for two SOC candidate species collected by LDWF using 4.9 m bag seine for years 1966 through 2007.

Table 5.5 Weighted means \pm 1 SE of temperature, salinity, and Secchi depth availabilities and uses by the two candidate species captured in the 16' otter trawl in coastal Louisiana, 1986-2007. *N* is the number of independent samples for the availability data and is the number of individuals captured for the two species.

Temperature	<i>N</i>	Mean \pm SE
Trawl Availability	38879	22.6 \pm 0.03
southern puffer	4614	25.8 \pm 0.06
Atlantic threadfin	78590	23.4 \pm 0.01
Salinity		
Trawl Availability	38830	12.4 \pm 0.04
southern puffer	4612	12.5 \pm 0.08
Atlantic threadfin	78369	16.1 \pm 0.02
Secchi depth		
Trawl Availability	38879	53.5 \pm 0.16
southern puffer	4614	40.8 \pm 0.32
Atlantic threadfin	78590	44.3 \pm 0.9

DISCUSSION

Two species, Atlantic threadfin and southern puffer, were identified as possible SOC's for further analyses based on their declining annual abundance patterns beginning in the early 1990s. For spatial abundance patterns, Atlantic threadfin had their highest abundances in central CSAs which were where southern puffer had their lowest abundances. For habitat suitability, the patterns were strong for all three environmental variables. They had significantly different selection patterns along all three gradients, but were most similar along the turbidity gradient.

Both species had high abundances prior to 1991, and sharp declines in abundance occurred at roughly the same time (Fig. 5.1). Prior to 1991, the abundance of Atlantic threadfin fluctuated annually. Periods of interannual variation in abundance were substantial, but not consistent. In older literature Atlantic threadfin has been characterized as abundant throughout Gulf coastal and open waters (Chittenden and McEachran 1976, Hildebrand 1954, McFarland 1963), but with widely varying annual abundances (Galloway and Strawn 1974, Ogren and

Brusher 1977, Reid 1955). Dentzau and Chittenden (1990) found that the highest abundances occurred in shallow waters of 5 m or less.

Southern puffer is known to inhabit bays, estuaries, and protected waters (Sedberry and Carter 1993). They are often found in shallow waters (Burklew and Mortan 1971, Shipp and Yerger 1969) and may occur near salt marshes (Nordlie 2003). Shipp and Yerger (1969) noted that their distribution in the Gulf of Mexico favors the eastern half, with few sightings in Louisiana (Hoese and Moore 1977, Jones et al. 2002). The LDWF data I reviewed showed that southern puffer was once more abundant in Louisiana's estuaries and coastal waters than previously reported, but also showed that their abundance has drastically decreased (Fig. 5.1).

The decreases in abundances of Atlantic threadfin and southern puffer were not correlated with any changes in the three environmental variables that were measured at capture sites or with climatic variables. Annual abundances of Atlantic threadfin, however, were negatively correlated with gulf MSE (Table 5.1). The sharp declines in abundances may be due to overfishing of prey (Jackson et al. 2001) and/or increased mortality of these species due to bycatch in the shrimp trawl fishery. There are insufficient data on the prey and predators of either species. Atlantic threadfin juveniles have been found in white and brown shrimp communities (Dentzau and Chittenden 1990) which could lead to these species being caught in shrimping trawls.

Atlantic threadfin had a strong pattern of temperature suitability (Fig. 5.2), and higher abundances during spring (Table 5.2). The increase in juveniles during winter and spring in Louisiana suggests that breeding most likely occurred during late fall and early winter. Elsewhere this species spawns from fall through spring (Dentzau and Chittenden 1990, Gunter 1938, Gunter 1945, Juneau 1975, Miller 1965, Reid 1955).

For southern puffer, the suitability increased as the temperature increased (Fig. 5.2) and is consistent with the highest abundances during summer (Table 5.2). The relatively high abundance of juveniles throughout the year suggests that spawning may occur year round. Springer and Woodburn (1960) concluded that southern puffer spawned in fall in the eastern Gulf of Mexico; however, Shipp and Yerger (1969) concluded that their breeding season in the Gulf of Mexico is from spring through fall and could possibly be year round.

The strong pattern of higher suitability for warmer temperatures may not be due to its importance in habitat selection, but rather a result of increased abundance due to breeding and recruitment during warm seasons. The lower percentages of adults in the data suggests that both species use the estuaries and coastal waters as breeding grounds and move into open waters as they grow (Dentzau and Chittenden 1990, Shipp and Yerger 1969).

Both salinity (Fig. 5.4) and Secchi depth (Fig. 5.5) may be important variables for habitat selection by juvenile southern puffer and Atlantic threadfin. The Atlantic threadfin had a wider range of higher salinity suitability. Southern puffer is broadly euryhaline being found in salinities ranging from 5 to 45 (Hoese 1960). In Louisiana, southern puffer and Atlantic threadfin had significantly different suitability patterns for Secchi depth. For southern puffer, suitability increased with increasing depth, and for Atlantic threadfin, suitability decreased with increasing depths. Measurements of water clarity were not extensively studied in previous literature for either of these species.

Southern puffer and Atlantic threadfin are candidates for consideration in Louisiana's species of concern listing. Both of species use the Louisiana estuarine and coastal waters as nursery habitats for their juveniles. The sudden decrease in abundance roughly two decades ago is cause for concern, especially since reason for their decreases have yet to be identified.

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CHAPTER 6. SUMMARY AND CONCLUSIONS

This study examined habitat suitability patterns and temporal and spatial abundance patterns for several species of concern (SOC) and other estuarine-dependent species. First, I compared the patterns of suitability and abundance for two unrelated SOC species, chain pipefish and violet goby, to two closely related species common in Louisiana's estuaries, gulf pipefish and sharptail goby, hoping to shed light on the causes in the low abundances of the SOC species. Second, I compared the patterns of suitability and abundance for three SOC fundulid species, diamond killifish, bayou killifish, and saltmarsh topminnow, to examine their environmental requirements and any similarities and differences among the three species. Finally, I used annual abundance patterns to screen for species that should be considered for SOC status and identified two species with declining abundances, Atlantic threadfin and southern puffer, for further analyses. Patterns of suitability and abundance were also examined for both of these species.

In the first part, two pipefish species, one SOC and the other common in this study did not have any strong similarities between their patterns of habitat selection for any of the environmental variables. Both species had strong patterns of suitability for salinity and Secchi depth. For chain pipefish, suitabilities for salinities were highest around 8 to 12 and for Secchi depths around 50 to 70 cm. For gulf pipefish, suitability decreased with increasing salinities and Secchi depths. Temperature suitability for both species showed weak patterns. The two pipefish species had no patterns of seasonal abundance. For spatial abundance, the chain pipefish was highest in central CSAs and gulf pipefish was highest in eastern CSAs.

The goby species in the first part had strong patterns of suitability for all three environmental variables. They had the highest suitability for temperatures around 18 to 22 °C, the suitability decreased as the salinity increased, and as Secchi depths increased. For sharptail

goby, the pattern of suitability for salinity was not as strong as for violet goby. They also had strong patterns of seasonal abundance with peaks during spring.

For the second part, all three fundulid SOC's had strong patterns of habitat suitability for all three environmental variables examined with one exception. The suitabilities increased with temperature, were highest for salinities around 8, and for Secchi depths around 100 cm. The saltmarsh topminnow did not show a strong pattern of suitability for Secchi depth. The fundulids also had strong patterns of seasonal and spatial abundance patterns with peaks in winter and for central Louisiana CSAs.

In the last part, the annual abundance patterns of several species were examined for decreases in abundance. Atlantic threadfin and southern puffer were identified for further analyses based on significant declines in abundance after 1991. The spatial abundance of Atlantic threadfin was highest in Terrebonne/Timbalier stratum where the abundance was lowest for southern puffer. For the habitat suitabilities, both species had strong patterns, but were significantly different. Atlantic threadfin had the highest suitability for temperatures around 22 °C, for salinities around 16 to 26, and suitability decreased with increasing Secchi depths. For southern puffer, the suitabilities increased as the temperatures increased, were highest around salinities of 10, and decreased with increasing Secchi depths.

VITA

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